# Efficiency Test of a 1100 K. W. Air Blast Transformer by The Calorimetric Method

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# EFFICIENCY TEST OF AN 1100 K. W. AIR BLAST TRANSFORMER BY THE CALORIMETRIC METHOD.

# A THESIS

PRESENTED BY

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[illegible]85
B-5

coil.

# TRANSFORMER EFFICIENCY TEST.

The object of this test was to secure a method of determining the losses of an air blast transformer by the temperature rise and quantity of air supplied.

The test was made at the Jackson Boulevard Sub-Station of the Chicago Edison Company on a G. E. A.B.H. - B2 - 1100 K. W. Transformer.

Energy is received by the transformer at 9,000 volts and stepped down to 186 volts after which it passes through a Regulator to a Rotary Converter. The primary side is connected three phase delta. The connection from the secondary side to the Rotary is six phase star. The accompanying diagram ( Plate 4. ) explains the connections.

The iron loss of transformer was determined by running the Rotary inverted at normal speed thus exciting the transformer from the secondary side. Wattmeters were connected to read the power in the three coils.

The temperature of the iron was determined by measuring the resistance of test coils placed in the ventilating ducts of the transformer. The openings of ducts in which coils were placed were stopped so that the temperature recorded was that of iron and not that of cooling air. The coils were made of number 36 wire and had a resistance of about 100 ohms. Instead of assuming a temperature coefficient the coils were calibrated in an electric oven and curves of resistance and temperature were plotted for each coil.

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The rise of temperature in the copper was determined by the change of resistance in the secondary winding. In order that the temperature might be determined under load conditions, connections were made from one phase of transformer under test to corresponding phase of Transformer No. 2 of the same capacity ( See Plate 3. ) The Brushes of Rotary number 2 were removed. Under these conditions the neutral points of the two coils were at same potential and by means of a storage battery connected to these points a direct current was caused to flow through the coils. The resistance of the circuit between neutral points and of leads were found by the fall of potential method. Knowing the resistance of auxilliary transformer the resistance of transformer under test can be calculated.

While the neutral points are theoretically at the same potential it was found that neutral point of transformer under test shifted on the load [illegible], [illegible] E.M.F. and current between the neutral points. On this account it was found inadvisable to use a milli-voltmeter [illegible] fall of potential, [illegible] a Leeds and Northrup Potentiometer was used. This being a zero method the presence of the Alternating E. M. F. did not affect results. An ammeter [illegible] milli-voltmeter were used to measure current in the neutral.

The variation of current between neutral points with the load is included in the data. See Data Page 20.

The air outlets of the transformer were covered with sheet iron hoods as shown in the accompanying photograph. The openings of hoods consisted of rectangular tubes in order to give parallel flow of air, [illegible]. The velocity of the air was measured by a set of pitot tubes and a differential draft gauge. The mean velocity was determined by plotting curves of the velocity in different sections and finding their mean with a planimeter.

Unit number 1 was chosen for the test because it was necessary [illegible] that the neutrals of the three phases be kept separate. Unit No. 1 is provided with a Switch so that it may be started from the A. C. end on one half voltage, [illegible] coil being brought up [illegible] switch.

## IRON LOSS

| Phase | Current | Volts | K.W. | Power Factor |
|---|---|---|---|---|
| A – A' | [illegible] | [illegible] | [illegible] | [illegible] |
| C' – C | [illegible] | [illegible] | [illegible] | [illegible] |
| B – B' | 205 | [illegible] | [illegible] | [illegible] |

Total loss = 18.6 K.W.

$$= \frac{18.6}{1100} \quad 1.69\%$$

$$18.6 \text{ K.W.} = \frac{18.6 \times 1000}{746} \times \frac{550}{778} = 17.6 \text{ B. T. U. per sec.}$$

## Copper Loss at Full Load.

### Resistance of Secondary Coils.

| Coil | Current | Drop | Resistance |
|---|---|---|---|
| 1 - 1 | 10 .6 | .0453 | .000417 |
| 1 - 2 | 108.2 | .0444 | .000410 |
| 2 - 1 | 105.8 | .0417 | .000394 |
| 2 - 1 | 104.5 | .0410 | .000392 |
| 2 - 2 | 105.2 | .0385 | .000366 |
| 2 - 2 | 104.8 | .0385 | .000367 |
| 3 - 1 | 109.0 | .0494 | .000453 |
| 3 - 1 | 108.4 | .0491 | .000453 |
| 3 - 2 | 108.4 | .0501 | .000462 |
| 3 - 2 | 107.5 | .0498 | .000463 |

Average resistance of 1/2 coil = .0004165 Ohms.

### Resistance between corners of delta.

### PRIMARY.

| Corners | I | E | R |
|---|---|---|---|
| 1 - 2 | 36.8 | 27.0 | .734 |
| 1 - 2 | 36.8 | 27.1 | .736 |
| 1 - 2 | 36.4 | 26.9 | .739 |
| 1 - 3 | 36.3 | 26.9 | .741 |
| 1 - 3 | 36.7 | 27.0 | .736 |
| 1 - 3 | 36.7 | 26.9 | .733 |

Average = .7365

The resistance between corners of delta is the combined resistance of two paths one containing one coil and the other two coils in series. If X is the resistance of coil and R the combined resistance

$$\frac{1}{R} = \frac{1}{X} \text{ plus } \frac{1}{2X} \qquad R = .7365$$

X = 1.104 ohms resistance of primary coil.

Current in secondary coil at full load

$$\frac{1100.0 \times 1000}{3 \times 186} = 1972 \text{ amperes.}$$

$I^2R$ loss in three secondary coils

~~= 3 x ( 1972 )$^2$ x .PPPRQYT~~

= 3 x ( 1972 )$^2$ x .0004165 x 2 = 9.71 K. W.

Current in primary coil

$$\frac{1100 \times 1000}{9000 \times 3} = 40.75 \text{ amperes.}$$

$I^2R$ loss in three primary coils

3 x ( 40.75 )$^2$ x 1.104 = 5.5 K. W.

Copper loss = 5.5 plus 9.71 = 15.21 K. W.

= 1.38 %

# IRON TEMPERATURES FULL LOAD

| Time | Resistance-Coils. | | | | | Temperature of coils | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ~~9.08~~ | # 1 | # 2 | # 3 | # 5 | # 6 | # 1 | # 2 | # 3 | # 5 | # 6 | Average |
| 9.08 | 101.3 | 100.4 | 97.0 | 99.0 | 96.0 | 63. | 66. | 61. | 62. | 59. | 62. |
| 10.30 | 104.9 | 104.5 | 101.5 | 102.7 | 100.4 | 81. | 81. | 79. | 79. | 84. | 81. |
| 11.00 | 106.5 | 106.2 | 103.2 | 104.4 | 103.0 | 89. | 90. | 97. | 89. | 98. | 92. |
| 11.30 | 107.4 | 108.1 | 104.8 | 105.0 | 104.0 | 94. | 99. | 101. | 91. | 104. | 98. |
| 12.00 | 108.2 | 109.4 | 105.8 | 105.6 | 105.5 | 98. | 105. | 107. | 94. | 112. | 103. |
| 12.30 | 108.7 | 110.5 | 106.7 | 106.1 | ———— | 100. | 111. | 111. | 97. | ---- | 105. |
| 1.00 | 109.0 | 111.0 | 107.5 | 106.9 | 107.0 | 102. | 113. | 116. | 101. | 120. | 110. |
| 1.30 | 109.3 | 111.8 | 107.7 | 106.7 | 107.0 | 103. | 117. | 117. | 100. | 124. | 112. |
| 2.05 | 109.5 | 112.0 | 108.0 | 107.2 | 108.0 | 104. | 118. | 118. | 103. | 126. | 114. |
| 2.35 | 109.8 | 114.0 | 107.6 | 106.6 | 108.2 | 105. | 128. | 116. | 100. | 127. | 115. |
| 3.00 | 109.9 | 112.2 | 108.3 | 107.1 | 108.5 | 106. | 119. | 120. | 102. | 129. | 115.5 |
| 4.00 | 109.7 | 113.9 | 108.5 | 107.2 | 108.8 | 105. | 127. | 121. | 102. | 131. | 117. |

Copper Temperature Rise Test Load 6,600. Amperes.

| | Temperatures | Start | Finish |
|---|---|---|---|
| Trans under test | Air at upper outlet | 18.8 | 35.5 |
| " " " | " " lower " | 18.8 | 35.0 |
| Auxiliary trans | " " upper " | 18.8 | 22.7 |
| " " | " " lower " | 18.8 | 26.1 |
| Duct temperature | | 18.8 | 21.6 |

| Time | Current | $C'_1$ to $C'_2$ E | Neut$_1$ to $N_2$ E | $C_1$ To $C_2$ E | R # 1 1/2 Coil | T. Rise Deg. C. |
|---|---|---|---|---|---|---|
| 10.20 | 244.0 | .1948 | .2970 | .1962 | .000419 | 8.0 |
| 10.50 | 232.5 | .1876 | .2862. | .1904 | .000425 | 11.7 |
| 11.12 | 227.5 | .1880 | .2841 | .1878 | .000428 | 13.6 |
| 11.20 | 226.4 | .1876 | .2839 | .1888 | .000428 | 14.2 |
| 11.30 | 224.9 | .1868 | .2832 | .1897 | .000425 | 11.7 |
| 11.40 | 223.3 | .1856 | .2820 | .1894 | .000426 | 12.3 |
| 11.50 | 221.8 | .1843 | .2803 | .1883 | .000426 | 12.3 |
| 12.00 | 220.3 | .1837 | .2782 | .1870 | .000425 | 11.7 |

Resistance of 1/2 coil #1 at 18.8$^{\circ}$ C. = .0004165

R. of paths in # 2 at 18.8$^{\circ}$ = .0002060

R. of paths in # 2 at 22.7$^{\circ}$ = .0002094

Pressure taps on # 1 underneath transformer at ends of coil.

See scheme of conections as shown PLATE 3

## Copper Temperature Rise Test .

### Load On ROTORY--8000 Amperes.

### Temperatures.

| Time | #1 Upper Outlet | #1 Lower Outlet | Duct | #2 Lower Outlet |
|---|---|---|---|---|
| 3.10 | 23.3 | 27.2 | 20.8 | |
| 3.40 | 32.5 | 31.4 | 21.6 | 24.1 |
| 4.10 | 38.3 | 34.4 | 21.6 | |
| 4.40 | 42.7 | 26.6 | 21.6 | 25.5 |

| | |
|---|---|
| R of path in No. 2 start | .0002084 |
| R " " " " 2 finish | .0002100 |

Pressure taps on No. 1 underneath transformer at ends of coil.

| Time | $C_1^1$ to $C_2^1$ Current | $C_1^1$ to $C_2^1$ Drop | $Neut._1$ to $Neut._2$ Current | $Neut._1$ to $Neut._2$ Drop. | $C_1$ to $C_2$ Current | $C_1$ to $C_2$ Drop. | Res. # 1 ½ 1/2 Coil | Temp. Rise. Deg. Cent. |
|---|---|---|---|---|---|---|---|---|
| 3.09 | 215.0 | .1742 | 215.8 | .2652 | 214.3 | .1753 | .000409 | 0 |
| 3.13 | 214.0 | .1734 | 212.9 | .2627 | 212.5 | .1737 | .000421 | 7.34 |
| 3.15 | 211.8 | .1723 | 210.7 | .2612 | 210.7 | .1727 | .000425 | 9.8 |
| 3.21 | 210.3 | .1716 | 210.3 | .2602 | 209.2 | .1718 | .000419 | 6.1 |
| 3.23 | 208.9 | .1708 | 208.5 | .2591 | 208.5 | .1714 | .000427 | 11.0 |
| 3.37 | 219.8 | .1791 | 217.3 | .2592 | 215.4 | .1762 | .000426 | 10.4 |
| 3.43 | 213.9 | .1740 | 200.6 | .2624 | 207.0 | .1685 | .000416 | 22.6 |
| 3.58 | 201.2 | .1646 | 200.4 | .2525 | 199.3 | .1631 | .000444 | 21.4 |
| 4.25 | 208.1 | .1697 | 206.3 | .2575 | 204.5 | .1670 | .000446 | 22.6 |
| 4.30 | 201.5 | .1643 | 199.7 | .2497 | 195.7 | .1605 | .000450 | 25.1 |
| 5.15 | 207.7 | .1656 | 205.8 | .2545 | 203.7 | .1652 | .000449 | 24.5 |
| 5.23 | 202.9 | .1617 | 201.7 | .2499 | 199.7 | .1611 | .000455 | 28.1 |
| 5.26 | 201.5 | .1621 | 200.0 | .2482 | 197.3 | .1604 | .000449 | 24.5 |
| 5.30 | 196.7 | .1589 | 195.7 | .2439 | 194.5 | .1586 | .000451 | 25.7 |

Rotary Load = 8000 amperes.

The tabulated readings shown on pages 15, 17, 19, 21, 23, 25 were taken at section a-a, b-b, as shown pn PLATE 1 without dotted extension on discharge tubes.

The constants K and K' for the lower and upper openings were obtained by extending these nozzles as shown on PLATE # 1. and comparing velocity heads as tabulated on pages 12 and 13.

The object of these extensions was to obtain a parallel flow of air past the pitot tubes.

The results with these extensions givee the true velocity heads.

The mean velocity head was determinedby dividing the cross section of the discharge duct into a large number of small areas at the center of each of which the tubes were located and a reading of the draft gauge taken.

Curves were plotted (PLATES 9 to 28 inclusive) and by integrating these curves the value of K was determined.

## DETERMINATION OF K. ( Data taken at a-a. )

|  | Horizontal |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| -- Vertical--- | 1/4 | 1/2 | 1 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
| qjw 1/2 | .14 | .16 | .20 | .23 | .23 | .32 | .33 | .37 | .26 |
| 1 | .16 | .18 | .17 | .21 | .22 | .26 | .51 | .40 | .31 |
| 2 | .20 | .19 | .21 | .22 | .26 | .73 | .41 | .51 | .44 |
| 3 | .26 | .26 | .28 | .29 | .23 | .42 | .58 | .64 | .59 |
| 4 | .37 | .41 | .42 | .46 | .49 | .54 | .72 | .78 | .72 |
| 5 | .43 | .52 | .54 | .62 | .65 | .72 | .77 | .85 | .74 |
| 6 | .42 | .52 | .63 | .69 | .78 | .81 | .84 | .81 | .75 |
| 7 | .37 | .46 | .56 | .61 | .72 | .78 | .85 | .79 | .72 |
| 8 | .32 | .40 | .38 | .50 | .61 | .73 | .76 | .76 | .70 |
| 9 | .27 | .30 | .35 | .33 | .43 | .56 | .59 | .56 | .55 |
| 9 1/2 | .24 | .28 | .33 | .34 | .40 | .51 | .52 | .40 | .55 |
| Mean $\sqrt{h}$ by planimeter | .52 | .575 | .588 : | .624 | .655 | .720 | .760 | .750 | .705 |

Mean $\sqrt{h}$ = .653

( See PLATES 9 to 18 inclusive.)

# DETERMINATION OF K ( DATA TAKEN AT a-a')*

| | Horizontal | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vertical | 1/4 | 1/2 | 1 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
| 1/2 | -.04 | -.05 | .22 | .45 | .53 | .57 | .78 | .76 | .71 |
| 1 | -.04 | -.04 | .24 | .50 | .65 | .69 | .78 | .78 | .74 |
| 2 | -.05 | -.05 | .26 | .53 | .77 | .80 | .84 | .78 | .74 |
| 3 | -.05 | -.01 | .26 | .58 | .75 | .77 | .80 | .83 | .80 |
| 4 | -.04 | .05 | .35 | .65 | .77 | .78 | .82 | .78 | .71 |
| 5 | .06 | .14 | .36 | .65 | .76 | .78 | .72 | .71 | .72 |
| 6 | .01 | .45 | .54 | .71 | .74 | .69 | .68 | .70 | .68 |
| 7 | .41 | .59 | .65 | .69 | .74 | .72 | .72 | .70 | .68 |
| 8 | .53 | .69 | .75 | .76 | .76 | .74 | .73 | .72 | .70 |
| 9 | .48 | .60 | .72 | .75 | .82 | .78 | .77 | .74 | .70 |
| 9 1/2 | .44 | .52 | .64 | .74 | .84 | .88 | .94 | .77 | .72 |
| Mean h by planimeter | .316 | .396 | .649 | .771 | .853 | .857 | .880 | .853 | .835 |

Mean h = .768

(See PLATES 19 to 28 inclusive )

## Calibration of Pitot Tubes with Standard.

| Run # | Draft Gauge |  | Actual Reading Inch. Water |  | Ratio of Gauge Used to Standard. |
|---|---|---|---|---|---|
|  | Standard | Gauge Used | Standard | Gauge Used |  |
| 1 | .82 | .37 | .34 | .33 | .972 |
| 2 | .87 | .41 | .39 | .37 | .948 |
| 3 | .93 | .46 | .45 | .42 | .935 |
| 4 | 1.02 | .55 | .54 | .51 | .945 |
| 5 | 1.11 | .67 | .63 | .63 | 1.000 |
| 6 | 1.22 | .78 | .74 | .74 | 1.000 |
| 7 | 1.34 | .91 | .86 | .87 | 1.060 |

Zero Reading of Standard Gauge = .48

" " " " " = .04

## AIR SUPPLY.

Determination of mean velocity at side opening. The velocityis proportional to the square root of the head. The velocity was found in inches of water and curves plotted with distance from side opening as abscissas and h as ordinates for different sections. The mean value of h was found from these curves for the different sections and final value obtained by plotting the mean value of the different sections.

Side Opening. ( Velocity heads in inches of water. )

Horizontal.

| Vertical | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
|---|---|---|---|---|---|---|---|
| 1/2 | .19 | .20 | .19 | .21 | .23 | .30 | .24 |
| 1 | .21 | .23 | .21 | .21 | .27 | .32 | .27 |
| 2 | .34 | .38 | .29 | .26 | .36 | .37 | .42 |
| 3 | .47 | .51 | .40 | .76 | .43 | .48 | .68 |
| 4 | .55 | .67 | .68 | .69 | .64 | .69 | .81 |
| 5 | .60 | .66 | .78 | .82 | .84 | .84 | .83 |
| 6 | .51 | .62 | .79 | .91 | .93 | .86 | .88 |
| 7 | .38 | .47 | .65 | .89 | .91 | .89 | .80 |
| 8 | .25 | .33 | .51 | .66 | .79 | .79 | .71 |
| 9 | .25 | .28 | .38 | .53 | .65 | .66 | .65 |
| 9 1/2 | .27 | .30 | .35 | .49 | .55 | .61 | .69 |
| Mean $\sqrt{h}$ by planimeter | .595 | .635 | .672 | .714 | .721 | .755 | .767 |

Mean $\sqrt{h}$ = .678 Actual $\sqrt{h}$ = .795 and h = .674 K = 1.173

Barometer readings in duct = 29.725, in room = 29.545

Temperatures, in " " =52.2 o F. " " = 87.0$^o$F.

Weight of air per cu. ft. at 29.545" pressure and 87°F.

$$\frac{.0864 \times 29.545 \times 461}{29.921 \times (461 \text{ plus } 87)} = .0716$$

Humidity in tunnel-- Wet Ther. = 35.8, Dry Ther. = 36.8°F.

Relative humidity = 73 %

Weight of liquid in saturated air at 52.2° F = .000627

$$.000627 \times .73 = .00046 \text{ \# per cu. ft.}$$

and $.00046 \times \frac{461 \text{ plus } 37}{461 \text{ plus } 87} = .00042$ # ∴ .0716 plus .00042 = .072#/cu, ft

Reducing inches of water to feet of air we have-

$.634 \times \frac{1}{12} \times \frac{62.3}{.072} = 45.75$ ~~5-ft.-per-sec.~~ ft. air.

Velocity = $\sqrt{2gh} = \sqrt{64.4 \times 45.75} = 54.2$ ft. per sec.

Area = $\frac{7 \times 11}{144} = .535$ sq. ft.

Quantity = .535 x 54.2 = 28.97 cu. ft. per sec.

In an adiabatic expansion the pressure varies as the cube of the absolute temperature

~~$P_m$&~~ $\frac{P_m}{P_n} = \frac{(T_m)^3}{(T_n)^3}$, $\frac{29.725}{29.545} = \frac{(513)^3}{(x)^3}$, $x = 51.2°$ F.

Temperature of air leaving = 87 hence rise = 87-51.2 = 35.8°F.

Specific heat at constant pressure = .2375

Weight of air = 28.97 x .0716 = 2.075 # per sec.

whence 2.075 x .2375 x 35.8 = 17.6 B. T. U. per sec.

Heat carried off by water:= 2897 x .00042 x 35.8 = .436 B. T. U. /sec.

Total B. T. U. from side opening :

17.6 plus .436 = 18.036 B. T. U. per sec.

## AIR TEST UPPER OPENING.

### Velocity heads in inches of water.

Breadth of duct

| Length | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
|---|---|---|---|---|---|---|---|
| 1 1/4 | .35 | .31 | .25 | .18 | .11 | .12 | .09 |
| 2 | .36 | .28 | .21 | .12 | .12 | .12 | .10 |
| 3 | .31 | .22 | .17 | .10 | .16 | .14 | .15 |
| 4 | .27 | .19 | .17 | .15 | .15 | .16 | .13 |
| 5 | .25 | .17 | .16 | .15 | .14 | .14 | .18 |
| 6 | .23 | .15 | .13 | .135 | .11 | .12 | .14 |
| 7 | .19 | .14 | .12 | .12 | .10 | .11 | .12 |
| 8 | .18 | .13 | .11 | .10 | .08 | .10 | .09 |
| 9 | .18 | .15 | .10 | .08 | .08 | .10 | .09 |
| 9 1/2 | .18 | .17 | .12 | .10 | .07 | .13 | .09 |

Mean $\sqrt{h}$ = .351 K = 1.173

Actual $\sqrt{h}$ = .412 h = .17

Barometer reading in duct = 29.725, in room = 29.545

Temperatures in duct = 52.2° F at upper outlet = 84.5° F.

Weight of air per cu. ft. at 29.545 inches pressure and at 84.5° F.

$$= .0864 \times \frac{29.545}{29.921} \times \frac{461}{545.5} = .072$$

Weight of vapor per cu. ft. when humidity is 75 % = .00042

Weight of mixture = .072 plus .00042 = .07242

Reducing ~~to~~ inches of water to ft. of air we have

$$.17 \times \frac{1}{12} \times \frac{62.5}{.07242} = 12.2 \text{ ft.}$$

Velocity = 2gh = 64.4 x 12.2 = 28 ft. per sec.

Quantity =

$$28 \times \frac{70}{144} = 13.6 \text{ cu. ft. per sec.}$$

and 13.6 x .072 = .98 # per sec.

.98 x .2375 x 33.3 = 7.74 B. T. U. per sec.

Heat carried off by moisture :

13.6 x .00046 x 33.3 = .208 B. T. U.

B. T. U. from upper opening :

7.74 plus .208 = 7.948 B. T. U. per sec.

Total B. T. U. carried away by air per sec.

18.036 plus 7.948 = 25.98 B. T. U. per sec.

## AIR TEST SIDE OPENING ( 7 x 11 )

### Velocity heads in inches of water.

Breadth of duct.

| Length | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
|---|---|---|---|---|---|---|---|
| 1/2 | .18 | .19 | .19 | .19 | .22 | .20 | .18 |
| 1 | .20 | .21 | .21 | .25 | .24 | .22 | .23 |
| 2 | .29 | .32 | .20 | .26 | .27 | .31 | .38 |
| 3 | .41 | .41 | .[illegible] | .30 | .57 | .47 | .51 |
| 4 | .49 | .65 | .62 | .52 | .59 | .64 | .66 |
| 5 | .52 | .70 | .68 | .67 | .71 | .72 | .74 |
| 6 | .44 | .65 | .78 | .87 | .83 | .75 | .77 |
| 7 | .38 | .52 | .64 | .73 | .87 | .78 | .78 |
| 8 | .25 | .35 | .51 | .64 | .75 | .66 | .76 |
| 9 | .21 | .31 | .42 | .52 | .59 | .67 | .58 |
| 9 1/2 | .21 | .29 | .38 | .47 | .48 | .53 | .60 |
| Average $\sqrt{h}$ by planimeter | .56 | .65 | .655 | .685 | .704 | .709 | .748 |

K = 1.173

Average $\sqrt{h}$ = .674

Actual $\sqrt{h}$ = .790  h = .625

Barometer reading in duct 29.6 in room = 29.43

Temperatures in duct = 82.6°F

are in outlet = 116.4° F.

Humidity in tunnel Wet ther. = 67.8 Dry ther. =51°F.

Relative humidity = 30 %

Weighy of air per cu. ft. at 29.43 in. pressure and 116.4°F. =

$$.0864 \times \frac{29.43}{29.921} \times \frac{461}{461 \text{ plus } 116.4} = .0679$$

Weight of liquid in saturated air at 82.6°F = .0016

$$.0016 \times 3 = .00048 \ \# \text{ per cu. ft.}$$

This will be $.00048 \times \frac{461 \text{ plus } 82.6}{461 \text{ plus } 116.4} = .00046$

Total weight = .0679 plus .00046 = .06836 # per cu.ft.

The mean velocity head = $(.79)^2$ inches of water

Reducing this to ft. of air we have

$$(.79)^2 \times \frac{1}{12} \times \frac{62.3}{.06837} = 47.5 \text{ ft. of air.}$$

Velocity = 2gh = 64.4 x 47.5 = 55.3 ft. per sec.

Area of opening $\frac{7 \times 11}{144}$ ~~h~~= .535 sq. ft.

In an adiabadic expansion the pressure varies as the cube of the absolute temperature.

$$\frac{P_m}{P_n} = \frac{(T_m)^3}{(T_n)^3} , \quad \frac{29.6}{29.43} = \frac{(543.6)^3}{(x)^3} , x = 542.6 \text{ abs.} = 81.6°F.$$

Temperature ~~being~~ leaving = 116.4 - 81.6 = 34.8°F. rise.

Specific heat at constant pressure = .2375

Weight of air = 29.6 x .0679 = 2.01 # / sec.

2.01 x .2375 x 34.8 = 16.65 B.T.U. per sec.

Heat carried off by water= 29.6x.00046x34.8 = .475 B.T.U. per sec.

Total B.T.U. from side opening:

~~QY~~ 16.65 plus .475 = 17.125 B.T.U. per sec.

## AIR TEST UPPER OPENING ( 7" x 10" )

**Velocity heads in inches of water.**

|  | Breadth of duct |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| Length | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
| 1 1/4 | .38 | .27 | .20 | .07 | .12 | .09 | .08 |
| 2 | .32 | .23 | .16 | .09 | .10 | .08 | .08 |
| 3 | .27 | .19 | .16 | .11 | .11 | .11 | .11 |
| 4 | .24 | .16 | .14 | .15 | .13 | .12 | .10 |
| 5 | .22 | .15 | .13 | .13 | .13 | .13 | .13 |
| 6 | .18 | .12 | .11 | .12 | .13 | .14 | .14 |
| 7 | .17 | .11 | .09 | .09 | .10 | .09 | .13 |
| 8 | .15 | .11 | .09 | .07 | .09 | .07 | .09 |
| 9 | .15 | .10 | .09 | .07 | .07 | .08 | .08 |
| 9 1/2 | .14 | .13 | .11 | .08 | .06 | .08 | .06 |
| Average $\sqrt{h}$ by planimeter | .49 | .407 | .368 | .302 | .328 | .318 | .314 |

Average $\sqrt{h} = .368$ $h = .1355$ $K = 1.173$

Actual $\sqrt{h} = .432$ $h = .182$

Barometer in duct = 29.6, in room = 29.43

Temperatures in duct = 82.6°F in upper opening = 118.4°F

Humidity in tunnel Dry thermometer = 67.8° F. Wet thermometer = 51.°F

Humidity ( Relative ) = 30 %

Weight of air per cu. ft. at 29.43 inches pressure and 112.3$^{\circ}$

$$.0864 \times \frac{29.43}{29.921} \times \frac{461}{461 \text{ plus } 112.3} \equiv .0683$$

Weight of vapor per cu. ft. of saturated air at 67.8$^{\circ}$ = .0016

30 % x .0016 = .00048 # per cu,ft.

This would be $\frac{.00048 \times 461 \text{ plus } 82.6}{461 \text{ plus } 112.3} = .00046$ # per cu.ft.

at 116.4$^{\circ}$.

.0683 plus .00046 = .0684 # weight of vapor and air.

Mean velocity = $\sqrt{\frac{64.4 \times .182 \times 62.3}{12 \times .0688}} = 29.5$ ~~plus~~ f. p. s.

Quantity = $29.5 \times \frac{70}{144} = 14.45$ cu. ft. per sec.

Weight of air discharged per sec. 14.45 x .0683 =.987#per sec.

raised 29.6$^{\circ}$

B. T. U. ~~#~~=.987 x .2375 x 29.6 = 6.91 B. T. U.

Weight of moisture = 14.45 x .00046 = .00665

.00665 x 29.6 = .197 B. T. U. per sec.

6.91 plus .197 = 7.107 B. T. U. per sec.

Total B. T. U. carried away by the air per sec. =

17.125 plus 7.107 = 24.23 B. T. U.

## AIR TEST UPPER OPENING.

### Velocity heads in inches of water.

Breadth of duct in inches.

| Vertical | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
|---|---|---|---|---|---|---|---|
| 1/2 | .125 | .240 | .320 | .210 | .240 | .340 | .340 |
| 1 | .240 | .250 | .220 | .230 | .250 | .350 | .420 |
| 2 | .300 | .270 | .270 | .310 | .290 | .420 | .520 |
| 3 | .590 | .380 | .380 | .390 | .510 | .610 | .660 |
| 4 | .590 | .530 | .520 | .600 | .630 | .720 | .690 |
| 5 | .660 | .720 | .720 | .770 | .770 | .750 | .700 |
| 6 | .680 | .800 | .820 | .820 | .760 | .720 | .680 |
| 7 | .690 | .800 | .790 | .790 | .700 | .610 | .580 |
| 8 | .620 | .770 | .700 | .670 | .600 | .510 | .480 |
| 9 | .520 | .560 | .510 | .510 | .470 | .450 | .380 |
| 9 1/2 | .480 | .460 | .430 | .450 | .390 | .380 | .360 |
| Mean $\sqrt{h}$ by planimeter | .697 | .709 | .695 | .709 | .704 | .724 | .715 |

Average $\sqrt{h}$ = .708 , Actual $\sqrt{h}$ = .832 WHence h = .692 ( K ≠ 1.173 )

Barometer readings - in duct = 29.675 in room = 29.500

Temperatures -in duct = 84° Air leaving outlet = 117°F

Humidity in tunnel Dry thermometer = 78° F Wet thermometer = 67° F.

Relative humidity = 57 %.

Weight of air per cu. ft. at 29.5" pressure and 117° F =

$$.0864 \times \frac{29.50}{29.92} \times \frac{461}{461+117} = .0685 \ \# \text{ per cu. ft.}$$

Weight of liquid in saturated air at 78° F = .00158 #

Weight of liquid in 57° saturated air = .0009 #

This would amount to $.0009 \times \frac{461+78}{461+117} = .00084 \ \#$

Weight of air and liquid = .0693 #

Mean velocity =

$$= \sqrt{(64.4 \times \frac{.692}{12} \times \frac{623}{.0693}} = 57.7 \text{ ft. per sec.}$$

$$57.7 \times \frac{77}{144} = 30.8 \text{ cu. ft. per sec.}$$

and 30.8 x .0685 = 2.11 # per sec.

Tenperature of duct air after expansion 83° raised to 117°

B. T. U. carried off by air,

$$2.11 \times .2375 \times 34 = 17.8 \text{ B. T. U. per sec.}$$

Heat carried off by moisture in air

$$30.8 \times .00084 \times 34 = .879 \text{ B. T. U.}$$

Total B. T. U. per sec. from side opening,

$$17.8 + .879 = 18.679 \text{ B. T. U. per sec.}$$

## AIR TEST UPPER OPENING.

Velocity heads in inches of water

Breadth of duct.

| Length | 1/2 | 1 1/2 | 2 1/2 | 3 1/2 | 4 1/2 | 5 1/2 | 6 |
|---|---|---|---|---|---|---|---|
| 1 1/4 | .066 | .057 | .043 | .033 | .034 | .042 | .062 |
| 2 | .075 | .065 | .052 | .033 | .040 | .044 | .077 |
| 3 | .093 | .080 | .065 | .038 | .054 | .050 | .081 |
| 4 | .110 | .098 | .086 | .056 | .058 | .066 | .097 |
| 5 | .128 | .110 | .100 | .080 | .082 | .082 | .108 |
| 6 | .140 | .126 | .110 | .094 | .095 | .096 | .114 |
| 7 | .138 | .124 | .110 | .103 | .098 | .094 | .120 |
| 8 | .135 | .116 | .100 | .100 | .098 | .098 | .123 |
| 9 | .122 | .111 | .095 | .100 | .102 | .107 | .133 |
| 9 1/2 | .108 | .103 | .095 | .102 | .110 | .116 | .132 |
| Mean $\sqrt{h}$ by planimeter | .327 | .304 | .281 | .256 | .267 | .266 | .311 |

Average $\sqrt{h}$ = .286 h = .1125 K = 1.173

Actual $\sqrt{h}$ = .3355

Barometer reading in duct= 29.69, in room = 29.51

Temperaturein duct = 82.5°, in upper opening = 120° F.

Humidity in tunnel Dry Thermometer = 75°F, Wet Thermometer = 66°F

Relative Humidity = 63 %

Wt. of air per cu. ft. at 29.51" Bar. Pressure and 120°F=

$$.0864 \times \frac{29.51}{29.92} \times \frac{461}{461 \times 120} = .0682\#$$

Wt. of vapor per cu. ft. of saturated air at 75° = .0015

63 % x .0015 = .00095 # per cu. ft.

This would be $.00095 \times \frac{461 \text{ plus } 75}{461 \text{ plus } 120}$ ~~#~~= .00088 # per cu. ft. at 120° F.

.0682 plus .0009 = .0691 = Wt. of vapor and air.

Mean Velocity= $V\ 64.4 \times \frac{.1125}{12} \times \frac{62.3}{.0691} = 23.36$ f,p,s,

Quantity of air = $23.36 \times \frac{70}{144} = 11.32$ cu. ft. per sec.

Weight of air discharged per second =11.32 x.0682==

.774 # per second. raised 38.5°

B. T. U. = .774 x 38.5 x .2375 = 7.06

2 Weight of moisture.

11.32 x .0009 = .010188, .010188 x 38.5 = .392 B. T. U. / sec.

7.06 plus .392 = 7.452 B. T. U. per second.

Total B. T. U. carried away per second =

18.679 plus ~~B.~~ 7.452 = 26.131

## BALANCE OF ENERGY LOSS AND HEAT GAINED BY AIR .

Copper loss:

Load on Rotary 7200 amperes at 120 volts.

Assuming Rotary efficiency of 96%

Load on transformer = $\underline{7200 \quad x \quad 120}$ = 900 ~~KXW~~.K.W.

Secondary Loss:

Current = $\frac{900 \quad x \quad 1000}{186 \quad x \quad 3}$ = 1613 amperes

Loss = $3 \times (1613)^2 \times .0004165 \times 2 = 6.47$ K.W.

Prim. current = $\frac{900 \times 1000}{9000 \times 3}$ = 33.3 amperes

Prim. Loss = $3 \times (33.3)^2 \times 1.104 = 3.67$ K.W.

6.47 and 3.67 = 10.14 K.W.

$10.14 \times \frac{1000}{746} \times \frac{550}{778}$ = 9.61 B.T.U. per sec.

Iron loss = 17.6 B.T.U. per sec.

9.61 plus 17.60 = 27.21 B.T.U. per sec. lost in the transformer.

Average heat carried out by air =

26.13 B.T.U. per sec.
24.23 B.T.U. " "
25.98 B.T.U. " "

25.45 B.T.U. per sec.

The heat carried away by conduction through the copper leads extending through the base of the transformer is exceedingly small as shown by the following calculation

$$Q = \frac{K A ( t^1 - t^2)}{d}$$

$$K = 1.041 ( 1 - ct) = 1.041 ( 1 - .000039 \times 30) = 1.042$$

Hence $$Q = \frac{1.042( 1.335 \times 7)(2.54)}{23 \times 12 \times 2.54} \times \frac{30 \times 5}{9} = 1.49 \text{ Therms.}$$

The area of cross section of copper leads = 1.35 sq. inches.

The number of leads leaving the transformer = 7

Transformer coils are ~~28~~ 23 ft. long (end coils)

The equation as used above is in C. G. S. units and the factors 2.54. 12, and 5/9 are conversion factors.

Q = 1.49 Therms = ~~XRX~~ = .06 B.T.U.

The heat radiated from the case was found by calculation to be still smaller than that lost by conduction and hence may be neglected.

## Voltages Between Secondary Terminals.

### Transformer No. 1

| Terminals | Volts | Terminals | Volts. |
|---|---|---|---|
| A -- C | 93. | C'- B' | 164 |
| A - B | 158. | B - A' | 93 |
| A - A' | 188.5 | B - C | 164 |
| A - C | 157. | B - B' | 165 |
| A - B' | 92. | A'- C | 94 |
| C'- B | 92. | A'- B' | 166 |
| C'-A' | 160. | C - B' | 96 |
| C'- C | 186.5 | | |

## Voltages Between Secondary Terminals.

Transformer No. 2 with only C-C' phase excited. Exciting current equal to 160 amperes.

| Terminals | Volts | Terminals | Volts |
|---|---|---|---|
| A C' | 48. | C' B' | 134. |
| A A' | 89.5 | B A' | 89.5 |
| A B | 0. | B C | 134. |
| A C | 174. | B B' | 89.5 |
| A B' | 89.5 | A' C | 44. |
| C B' | 44. | A' B' | 0. |
| C' A' | 134. | C B' | 46. |
| C' C | 180. | | |

Variation of current in neutral between C C' phases of number 1 and number 2, with variation of load:

| Load Amperes | Neutral Currents |
|---|---|
| 1000. | 20. |
| 2000. | 27. |
| 3000. | 34. |
| 4000. | 44. |
| 5000. | 53. |
| 6000. | 60. |
| 7000. | 78. |

By taking a reading at the area which gives the mean of the velocity head determined as previously described, only one reading of the gauge is necessary. Hence to determine the lossesof a transformer it would only be necessary to take five readings, the temperature at the duct and the two points o of discharge. The humidity of the air would only be necessary in the calculations when extreme accuracy is required.

The value of such a method for factory or central station use is apparent since the test can be made under service conditions.

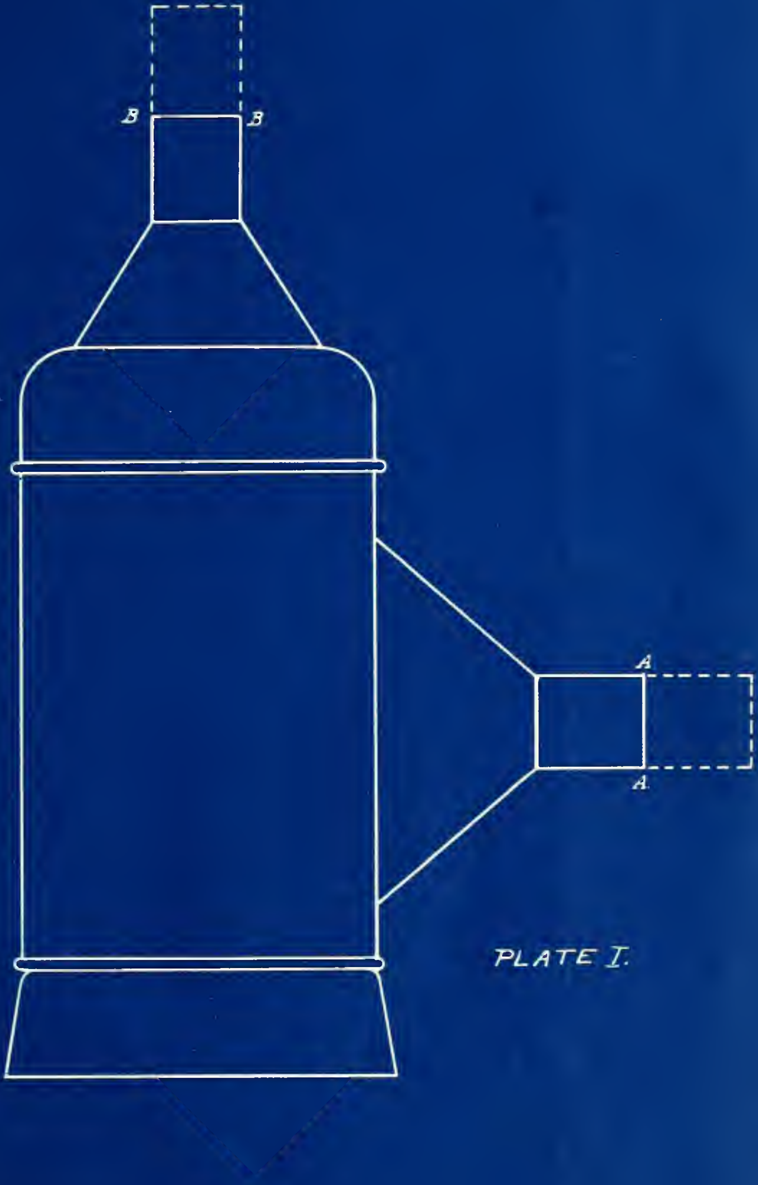


PLATE I.

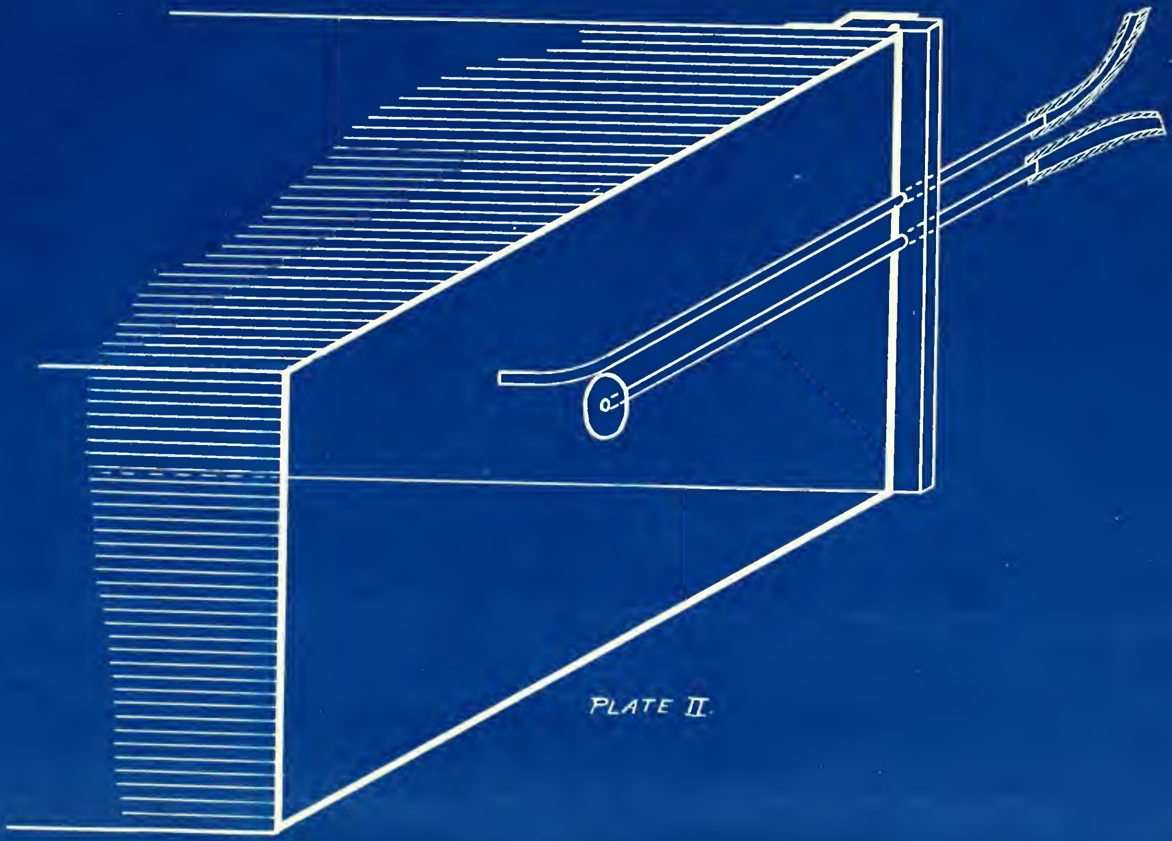


PLATE II.

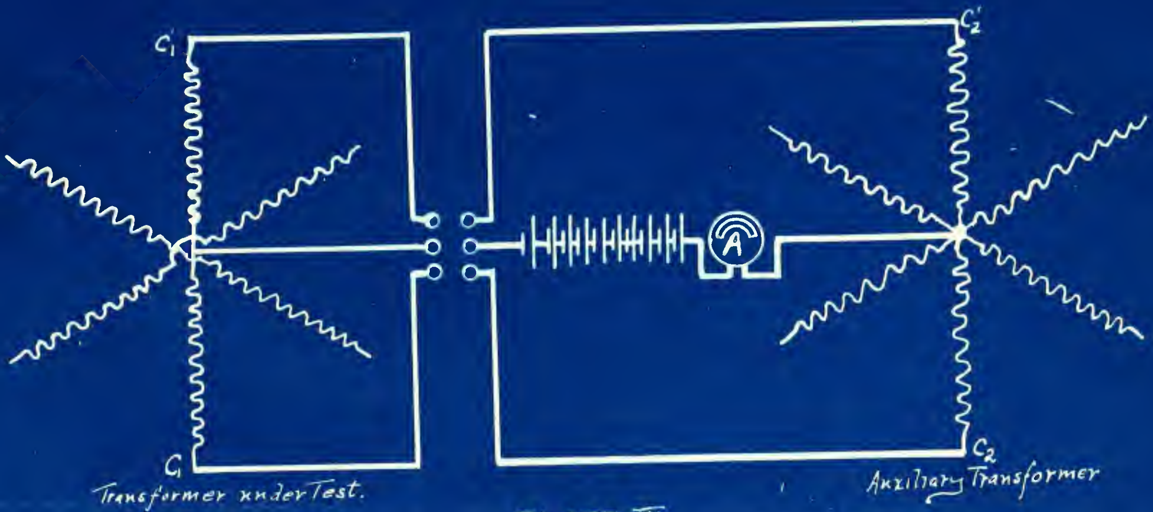
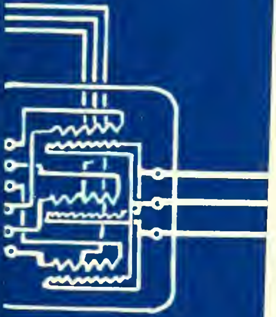
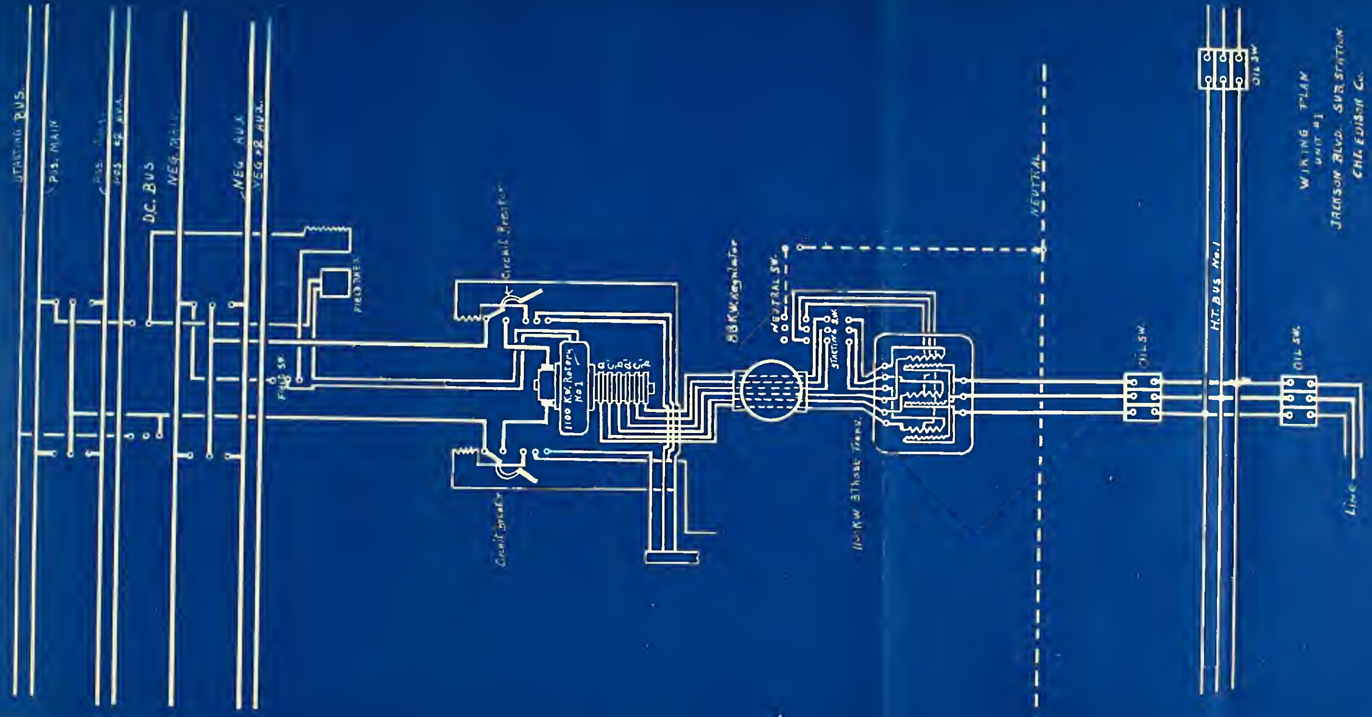


PLATE III





WIRING PLAN
UNIT #1
JACKSON BLVD. SUB STATION
CHI. EDISON Co.

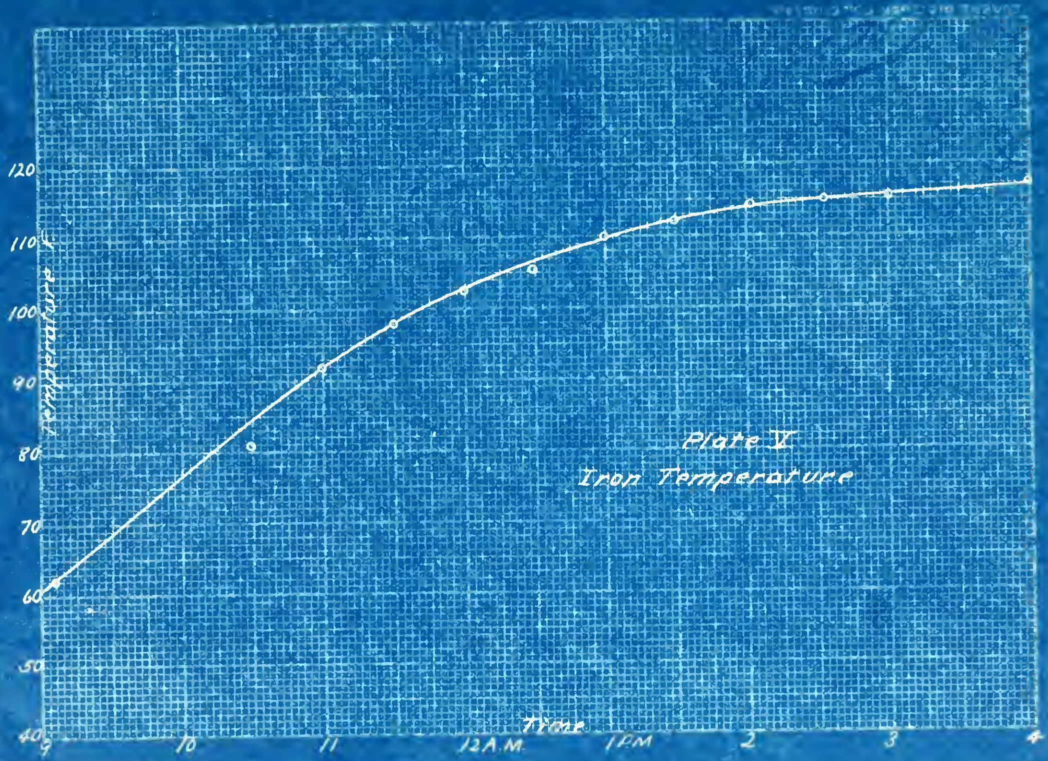


Plate V
Iron Temperature

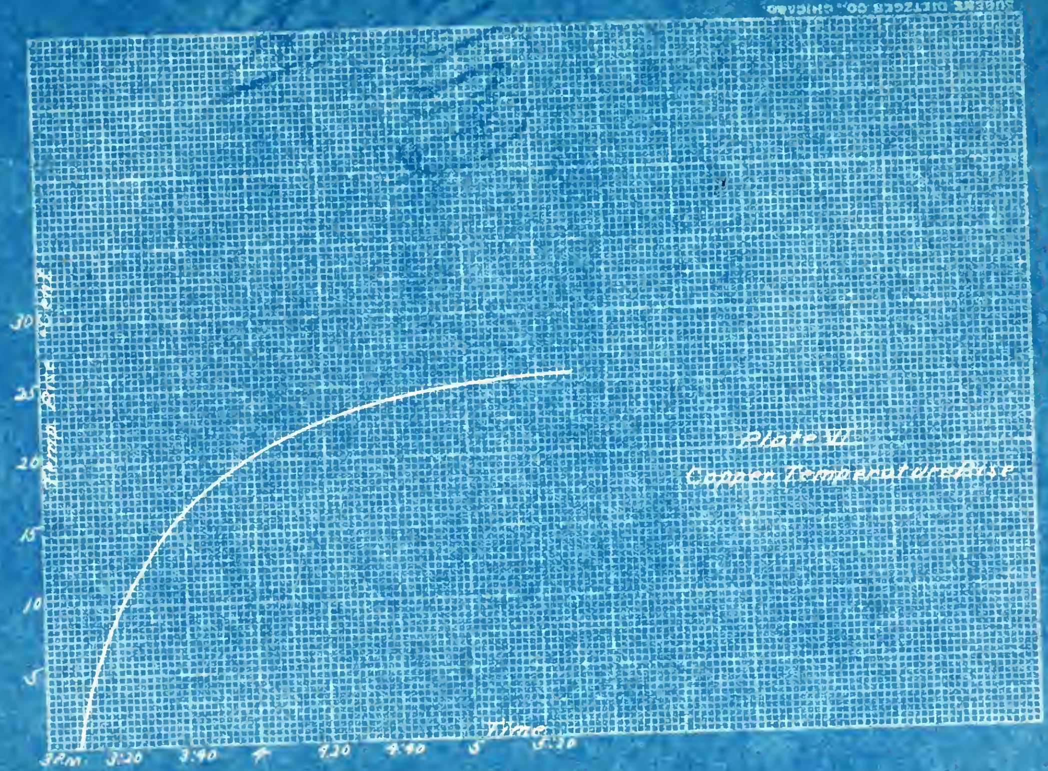


Plate VI

Copper Temperature Rise

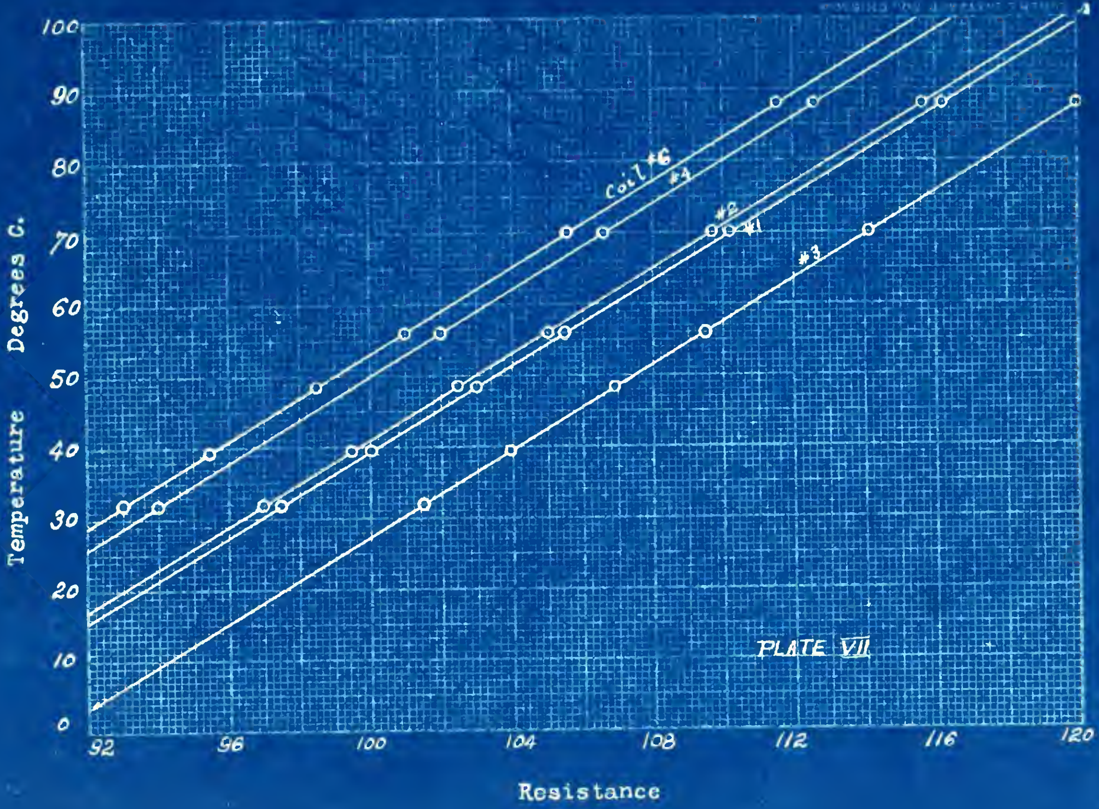


PLATE VII

Temperature Degrees C.
100
90
80
70
60
50
40
30
20
10
0
92
96
100
104
108
112
116
120
Resistance
Coil #6
#4
#2
#1
#3

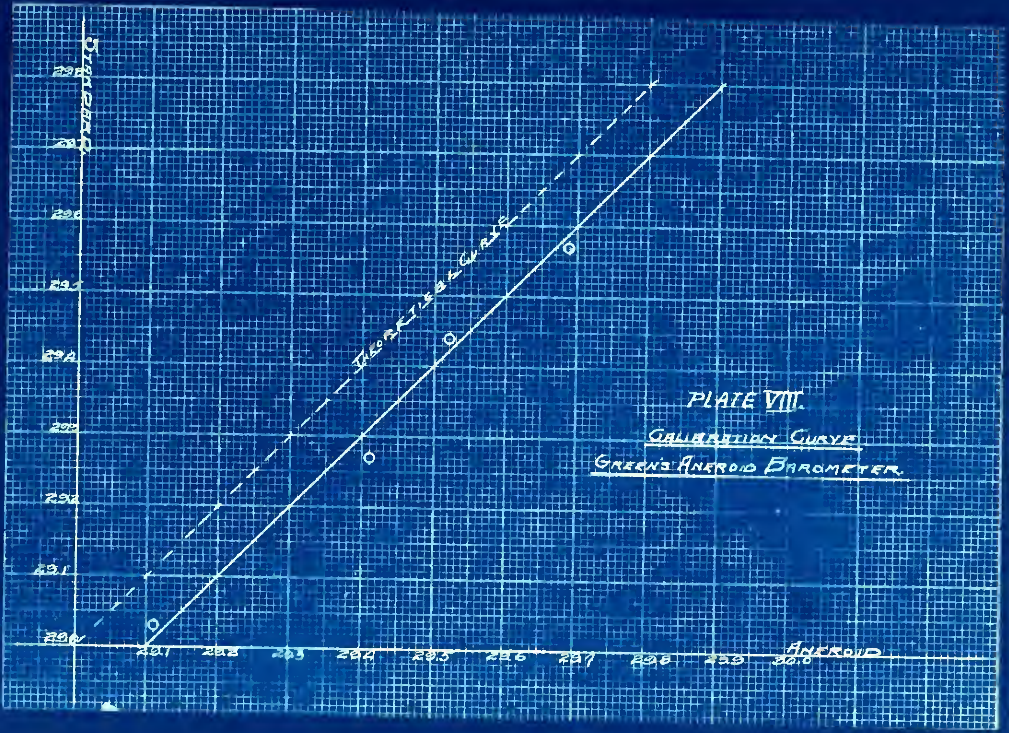


PLATE VIII.

CALIBRATION CURVE

GREEN'S ANEROID BAROMETER.

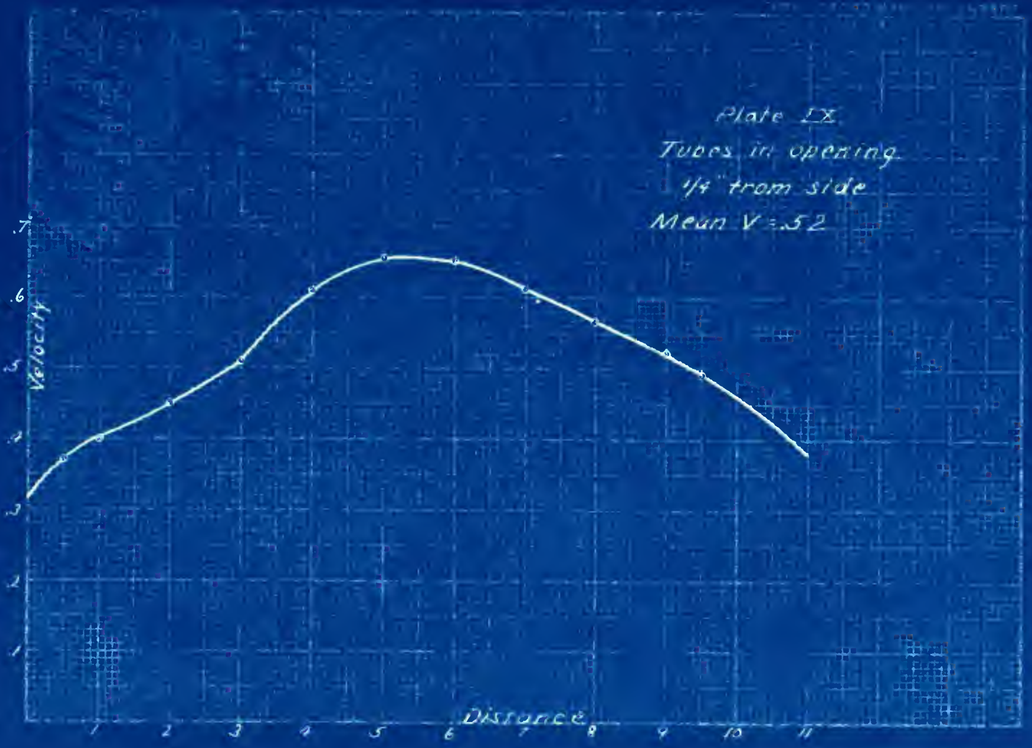


Plate IX

Tubes in opening

1/4" from side

Mean V = .52

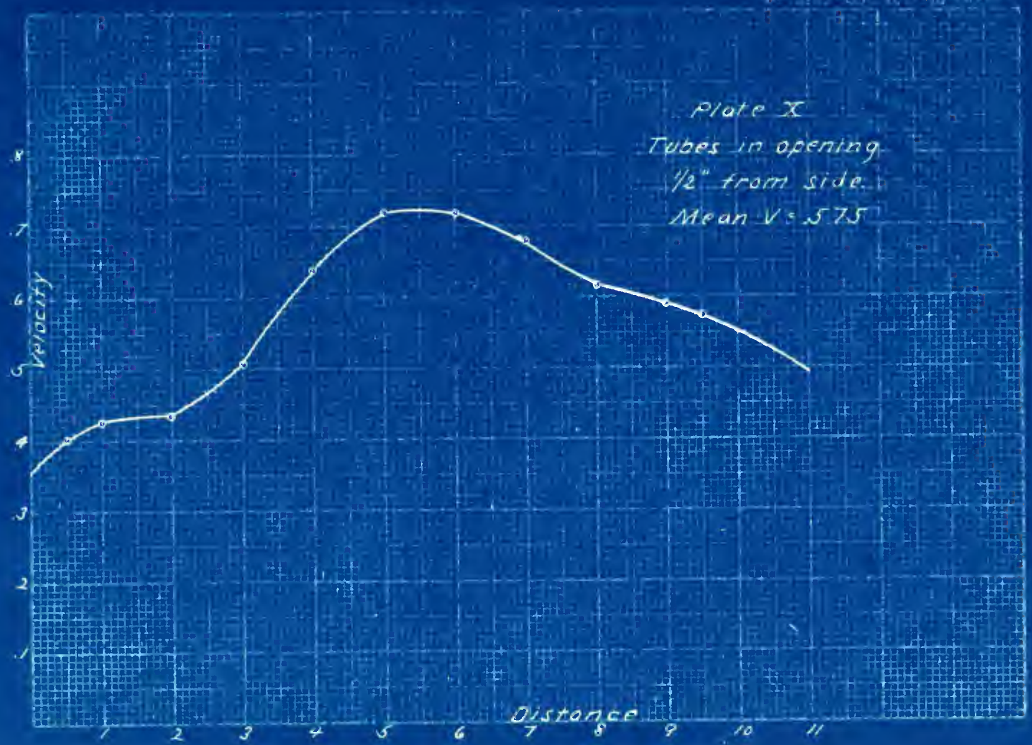


Plate X

Tubes in opening

1/2" from side.

Mean V = .575

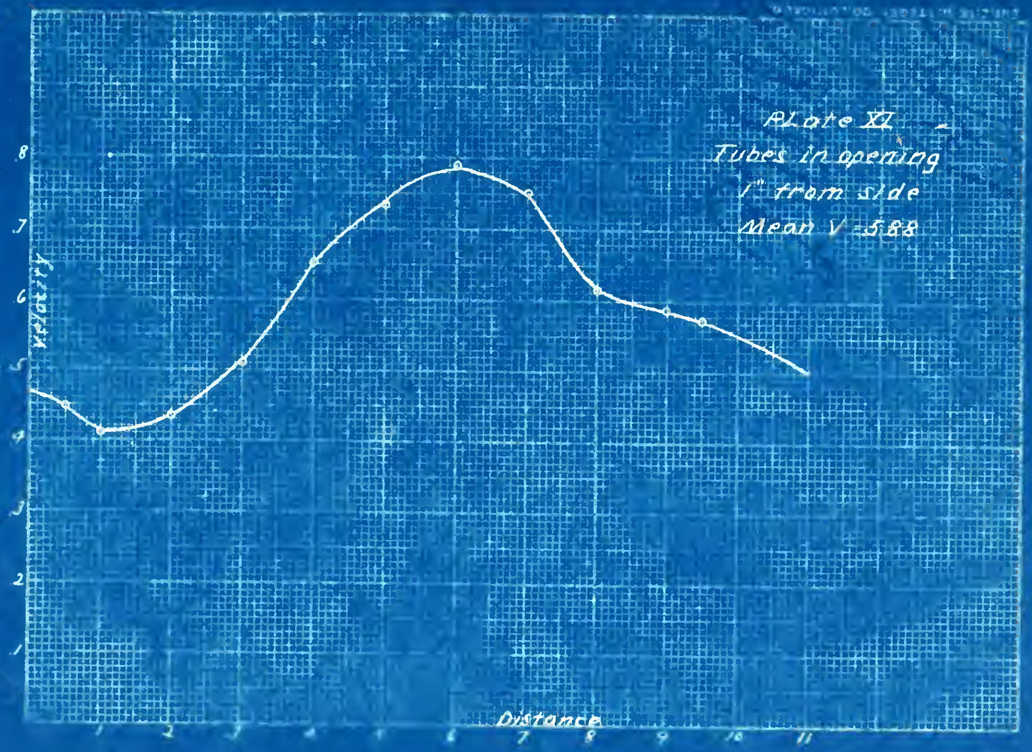


Plate XI
Tubes in opening
1" from side
Mean V .588

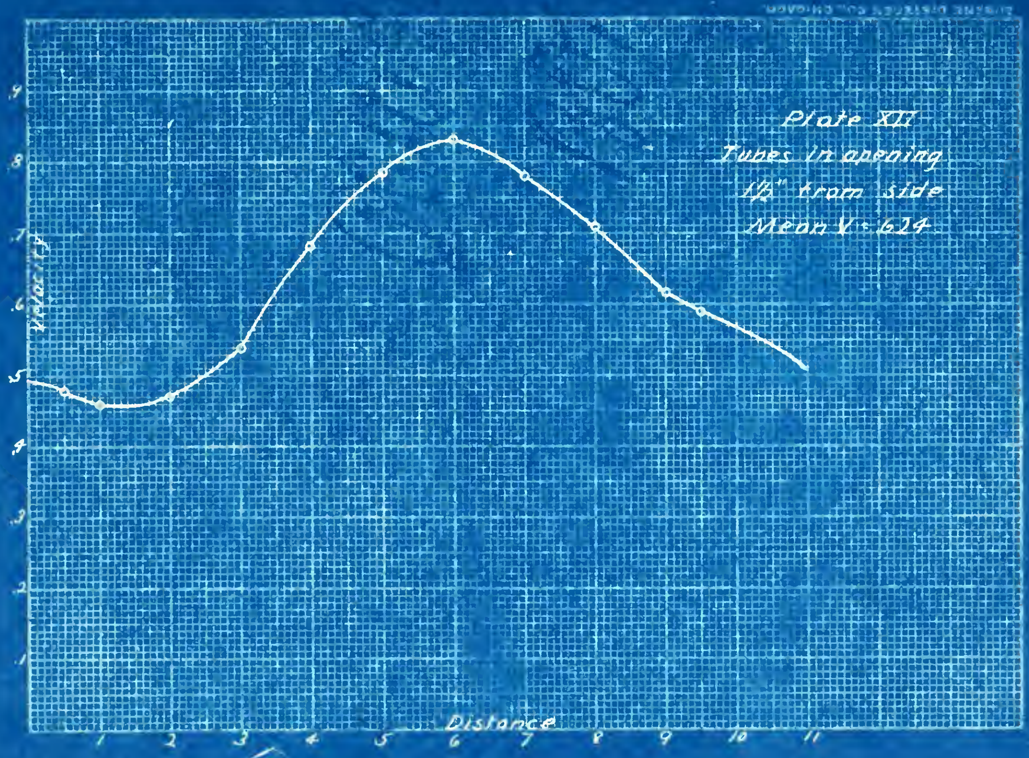


Plate XII
Tubes in opening
1½" from side
Mean V = .624
Velocity
.9
.8
.7
.6
.5
.4
.3
.2
.1
Distance
1
2
3
4
5
6
7
8
9
10
11
EUGENE DIETZGEN CO., CHICAGO.

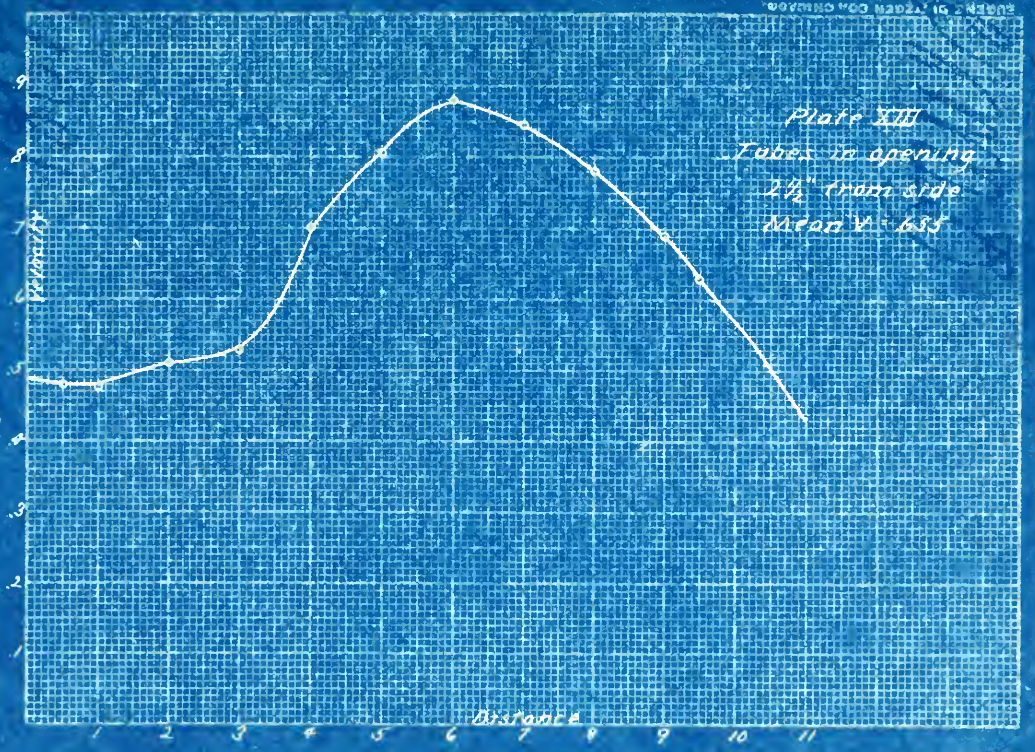


Plate XIII
Tubes in opening
2½" from side
Mean V = .685
Velocity
.9
.8
.7
.6
.5
.4
.3
.2
.1
Distance
1
2
3
4
5
6
7
8
9
10
11
EUGENE DIETZGEN CO., CHICAGO.

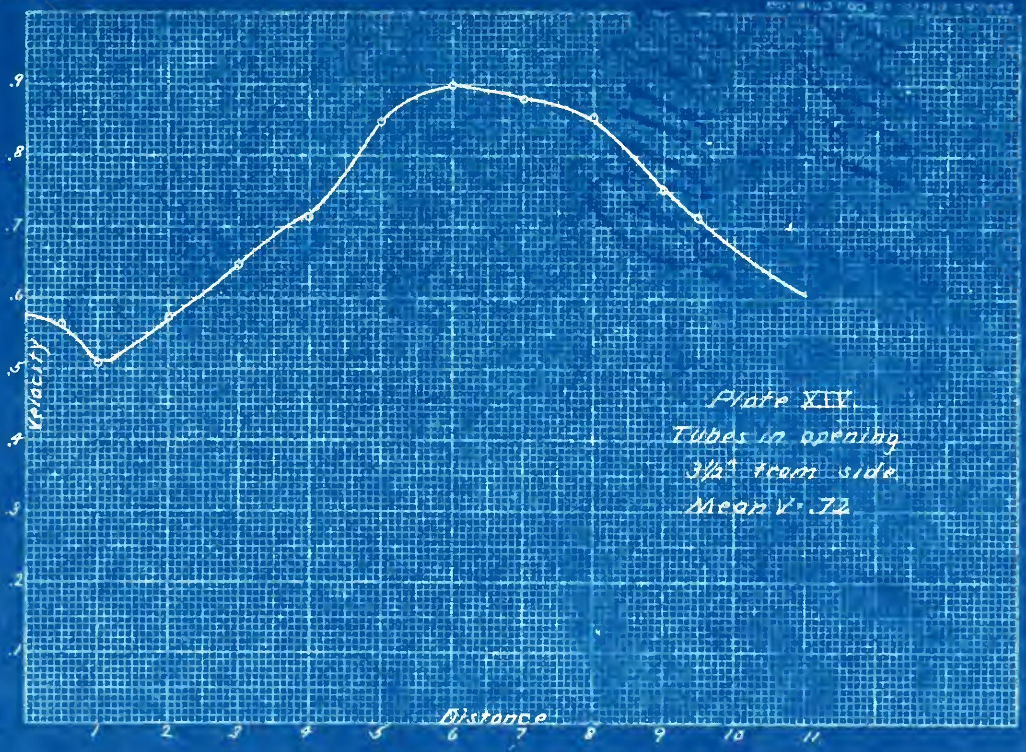


Plate XIV.
Tubes in opening
3½" from side
Mean V. .72

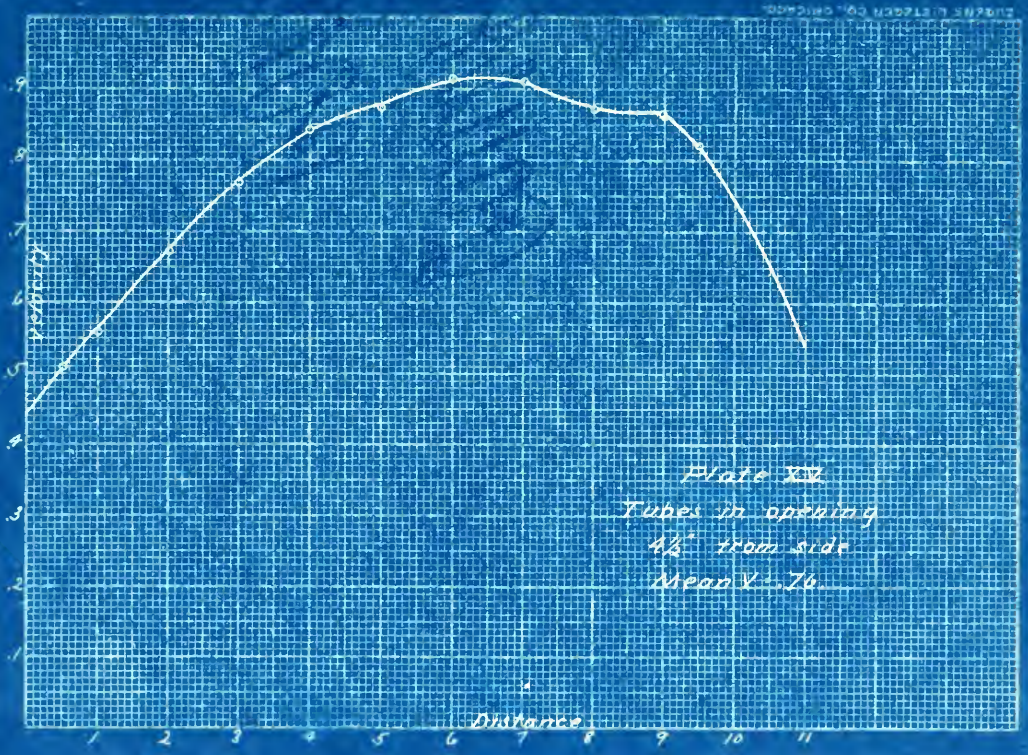


Plate XIV
Tubes in opening
4½" from side
Mean V = .76

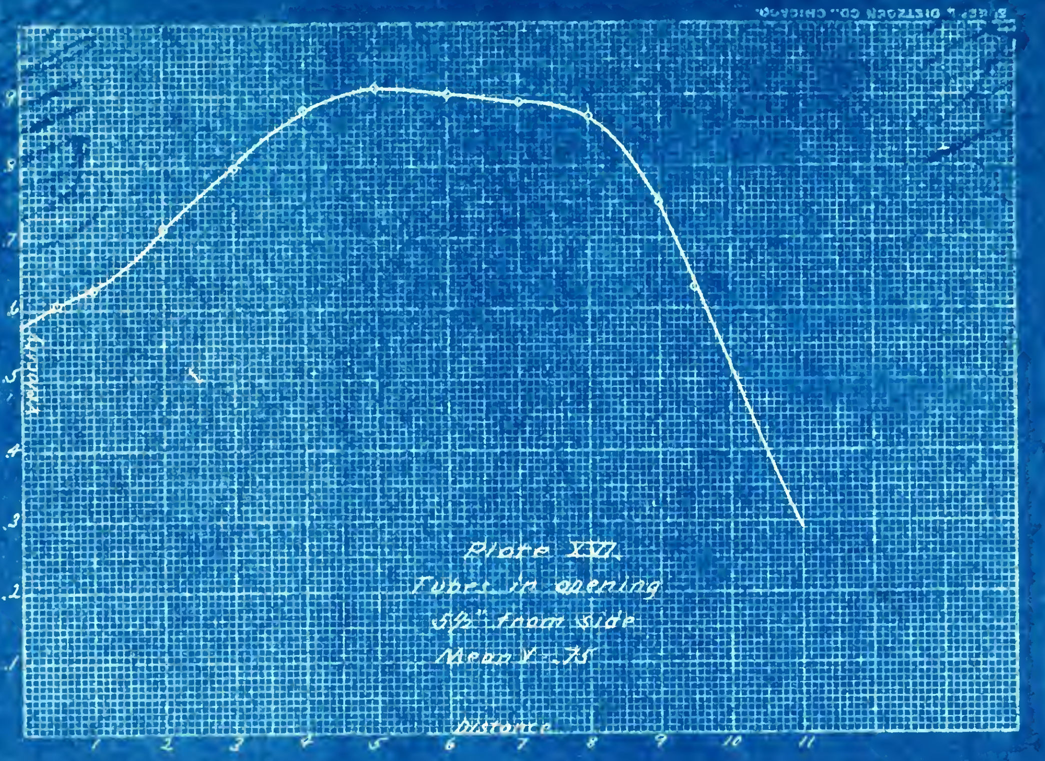


Plate XVI.

Tubes in opening

5½" from side

Mean V .75

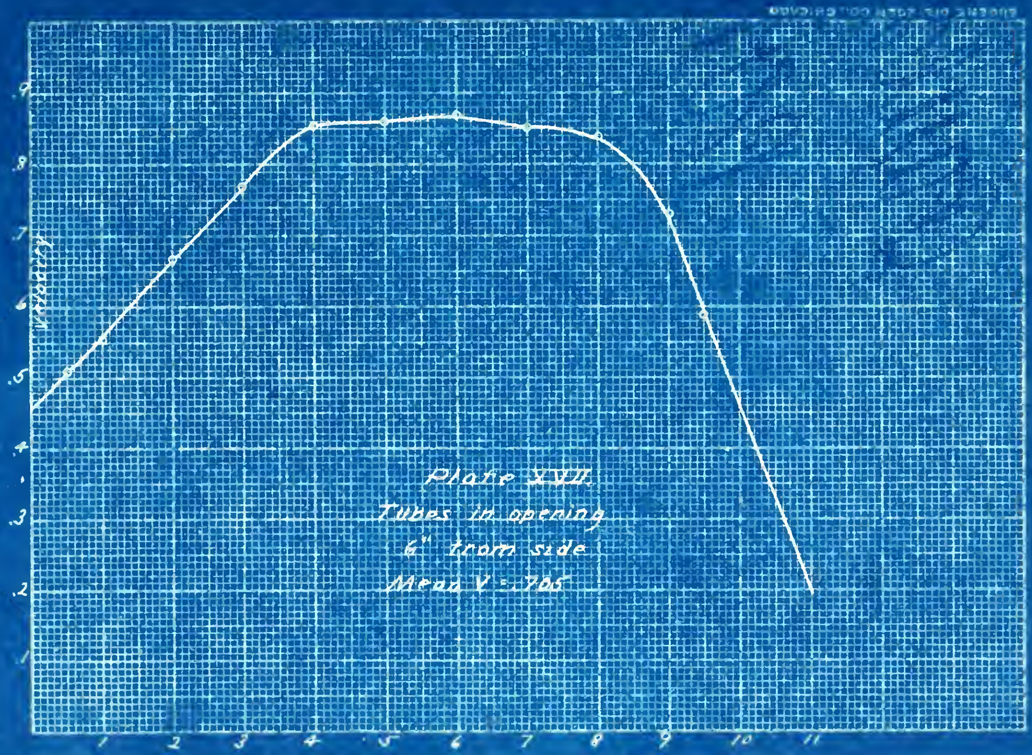


Plate XVII
Tubes in opening
6" from side
Mean V = .705

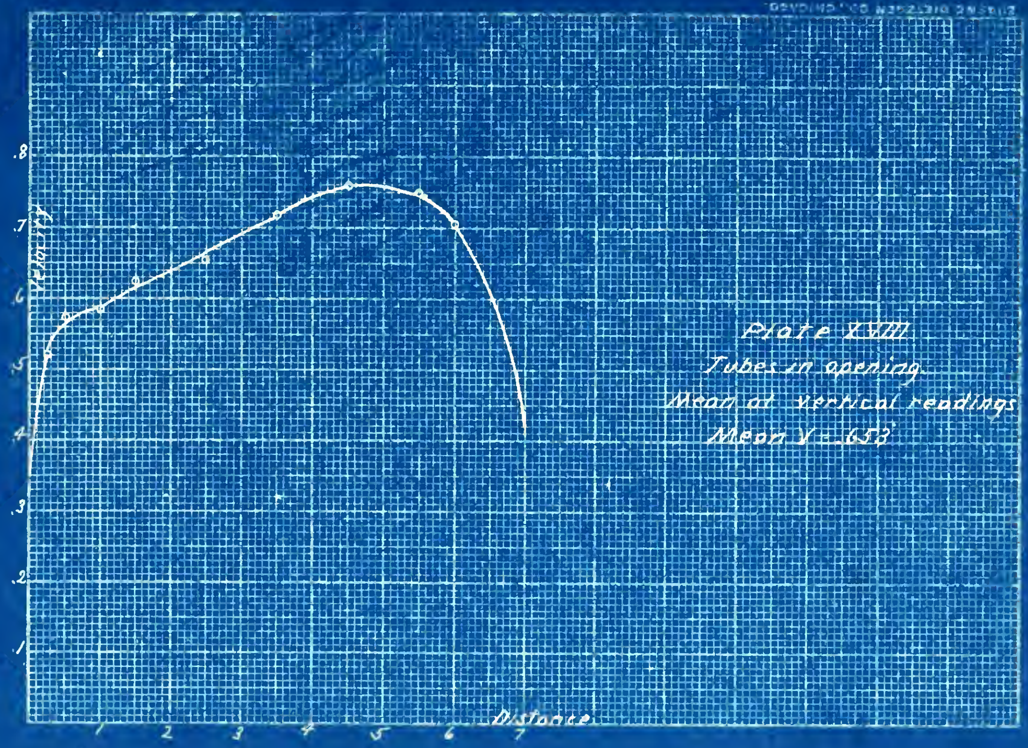


Plate XVIII

Tubes in opening.

Mean of vertical readings

Mean V = .653

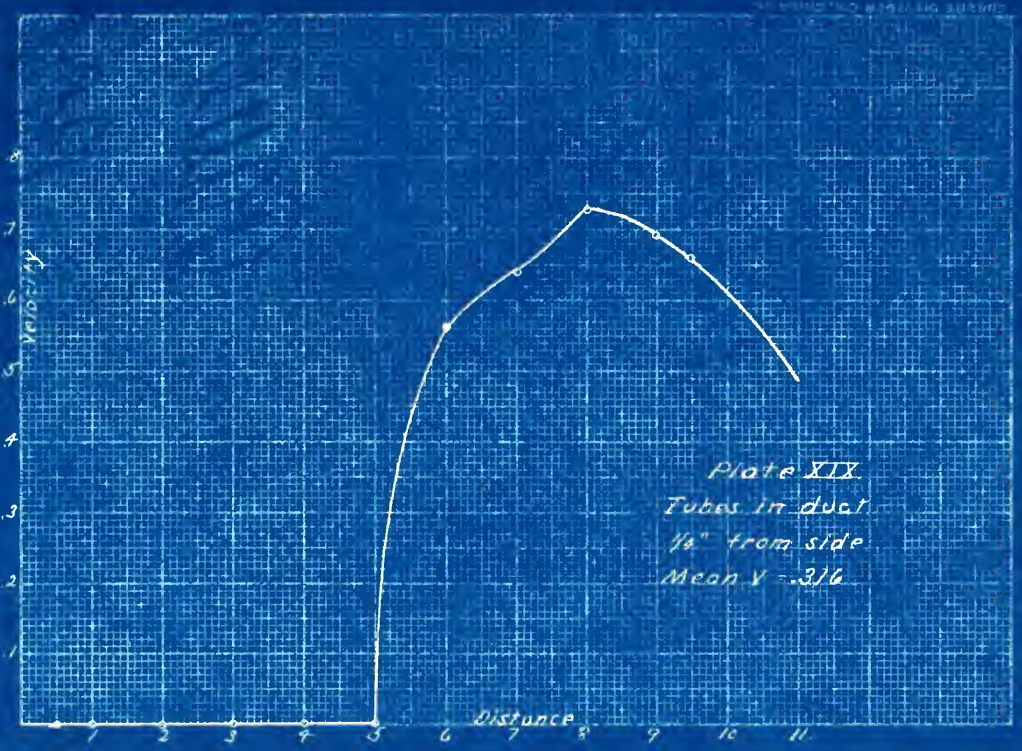


Plate XIX
Tubes in duct
1/8" from side
Mean V = .316

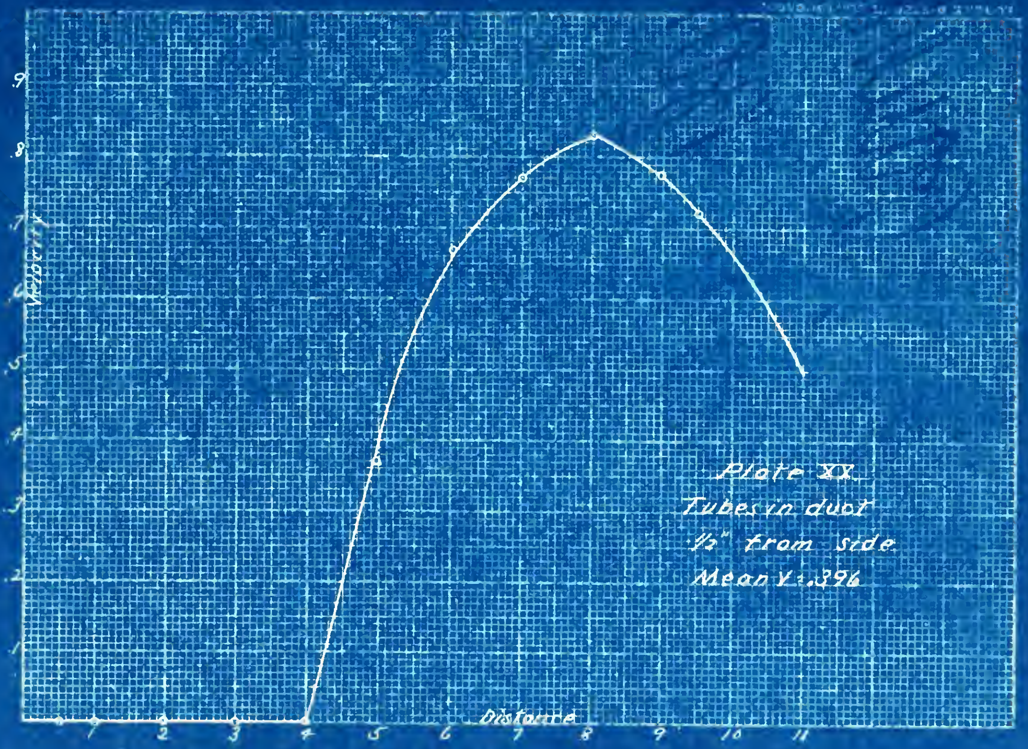


Plate XX
Tubes in duct
½" from side
Mean V = .396

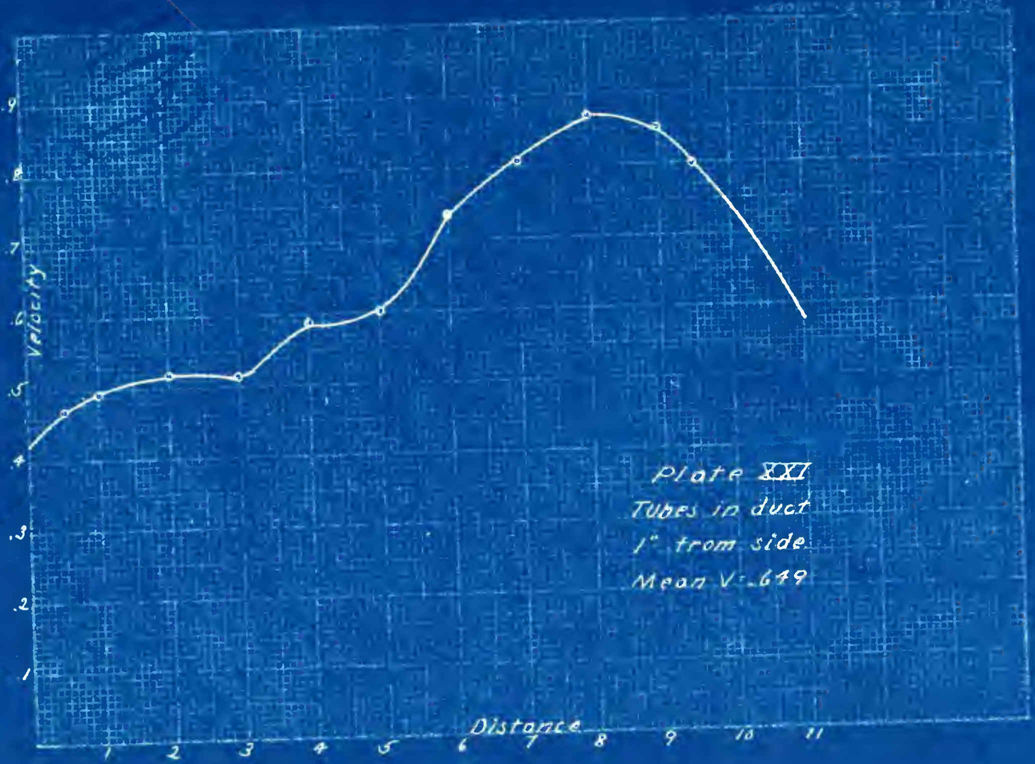


Plate XXI
Tubes in duct
1" from side
Mean V=.649

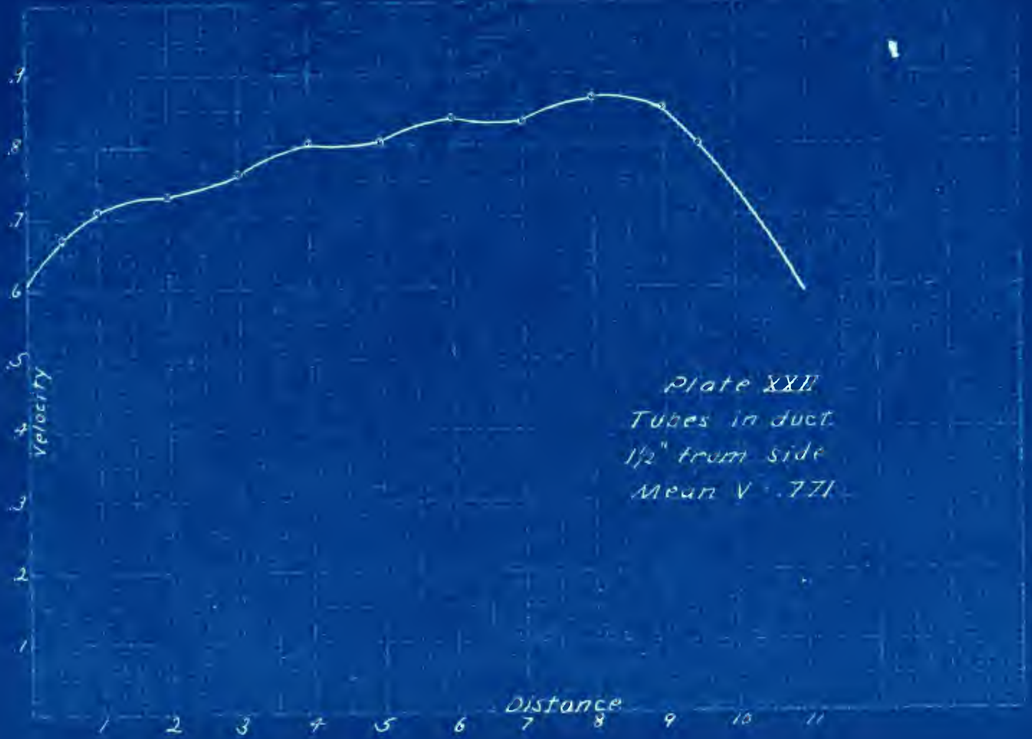


Plate XXII
Tubes in duct
1½" from side
Mean V = .771

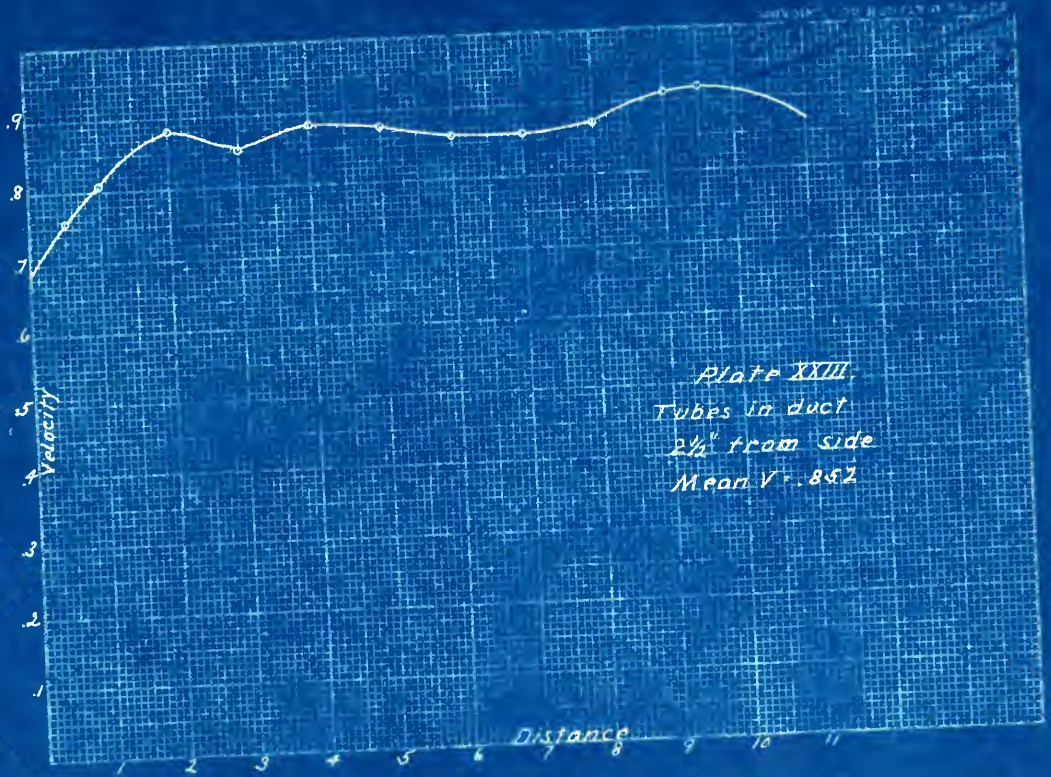


Plate XXIII.
Tubes in duct
2½" from side
Mean V = .852

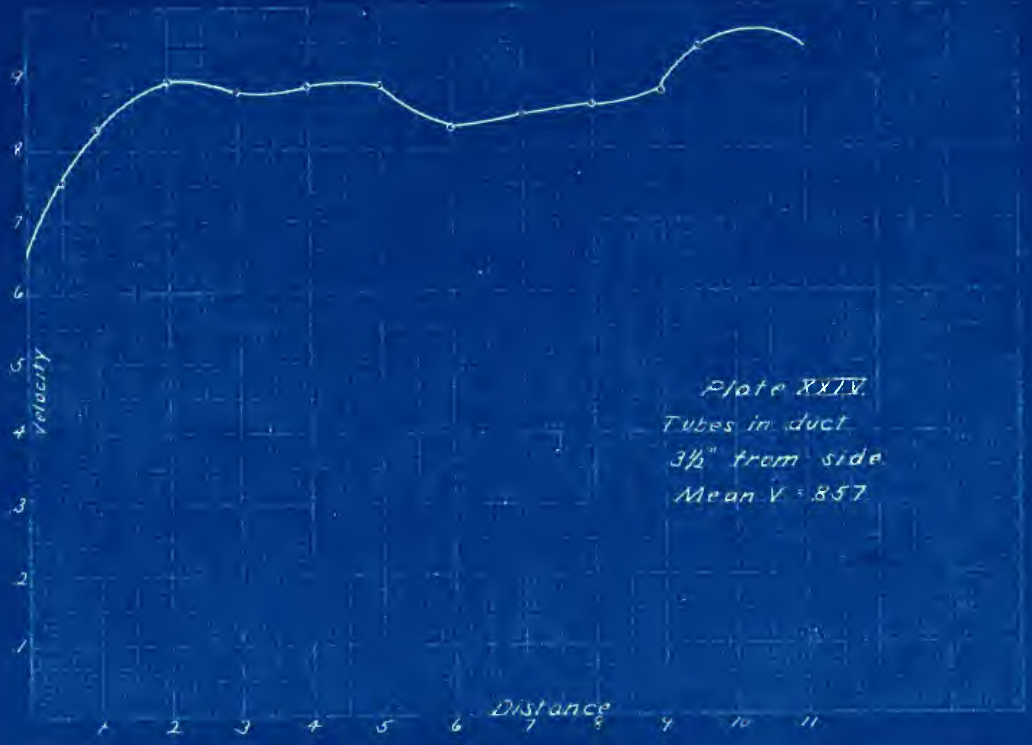


Plate XXIV.

Tubes in duct

3½" from side.

Mean V = .857

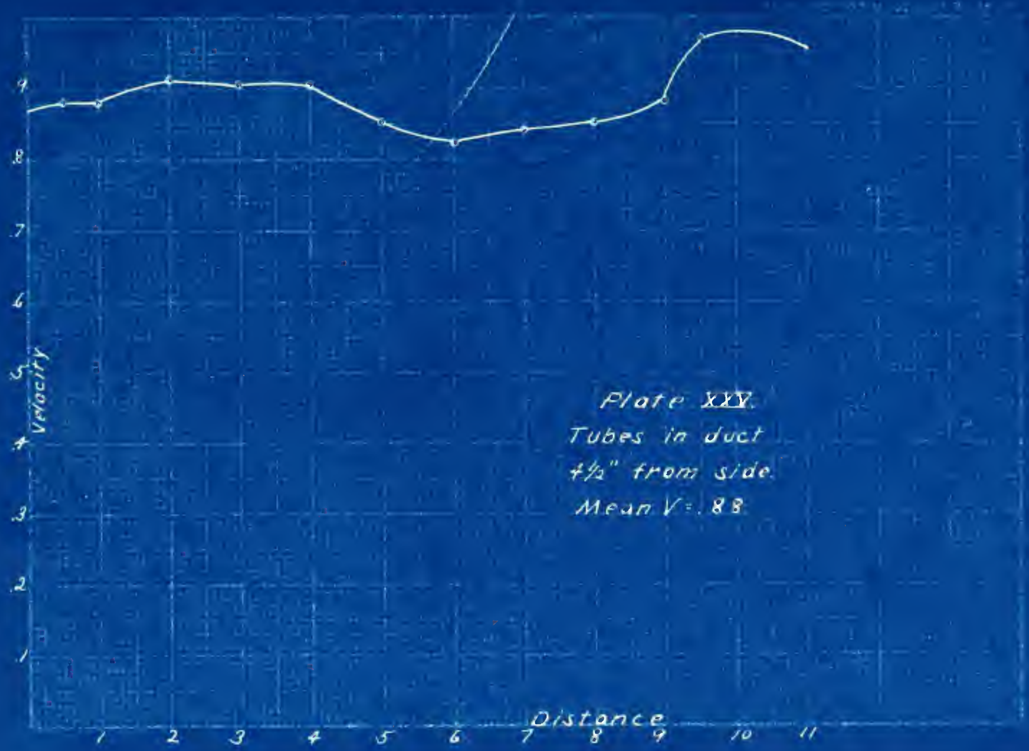


Plate XXV.
Tubes in duct
4½" from side.
Mean V = .88

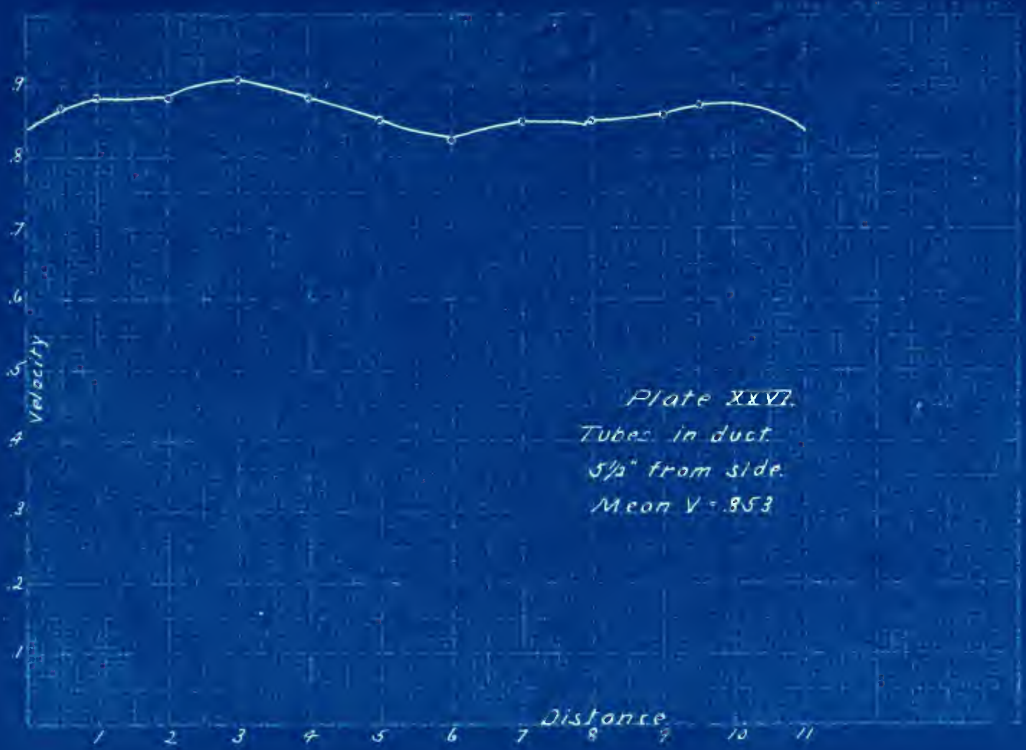


Plate XXVI.
Tubes in duct.
5½" from side.
Mean V = .853

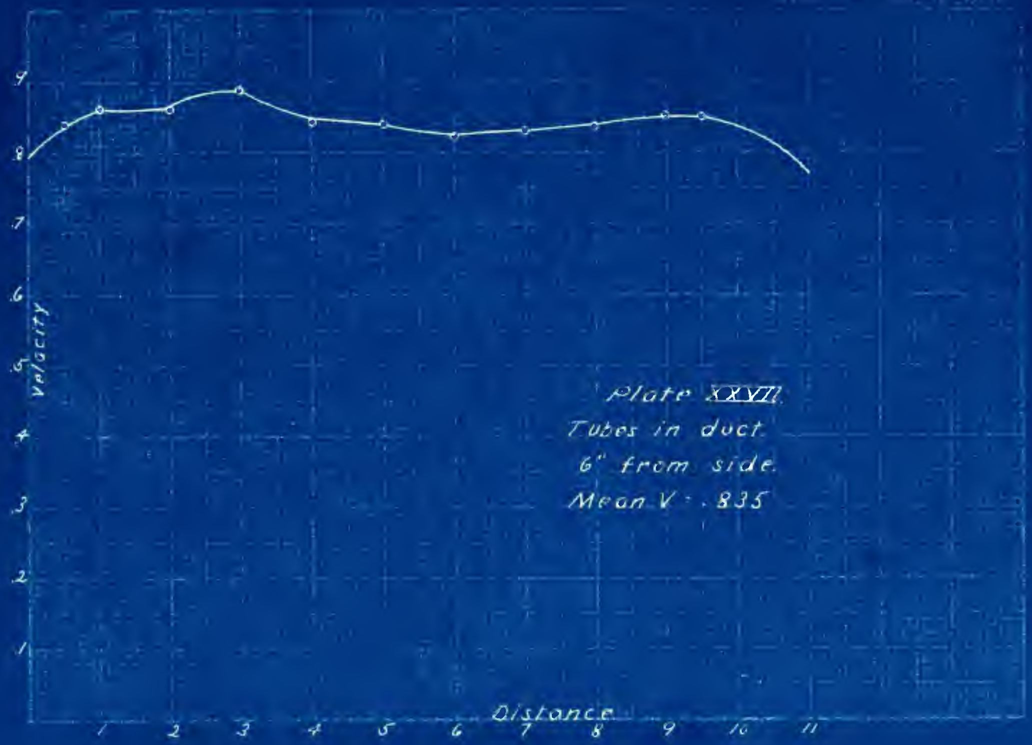


Plate XXVII

Tubes in duct.

6" from side.

Mean V = .835

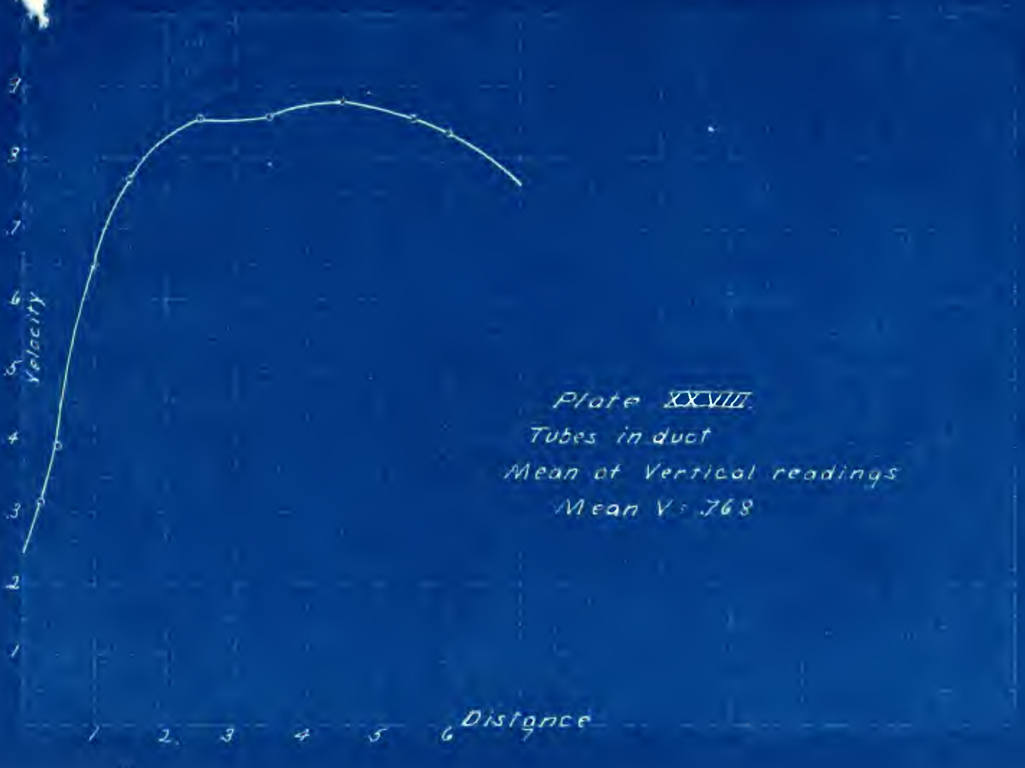


Plate XXVIII

Tubes in duct

Mean at Vertical readings

Mean V: .768